NATURAL PHILOSOPHY.

NOTE.

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The last three chapters on "LIGHT," by Mr. ROBERT HUNT, are added, to complete the course as it originally appeared.

NATURAL PHILOSOPHY.

BY

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TO WHICH ARE ADDED

THREE CHAPTERS ON "LIGHT,"

BY

ROBERT HUNT.

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NATURAL PHILOSOPHY.

By JOHN TYNDALL.

LESSON I.

1. When a boy hears a peal of thunder; when he sees a flash of lightning; when he watches the clouds forming, and views them afterwards discharge their contents of rain, hail, or snow; when he observes upon a winter morning the green fields covered with hoar-frost, and finds the same grass in summer adorned with pearls of dew; when he hears the melodious song of the lark, and observes the little bird securely floating in an atmosphere which is unable to support a straw; when he reflects upon the fire which warms him, and upon the flame which gives him light—there is nothing more natural than that he should desire to be instructed regarding the nature and causes of all these things. He sees a man fire a gun at a distance, notes the spark first and hears the sound afterwards, and the question arises, How is it that this difference is not perceived when he stands close to the gun? for then the sound and the spark occur simultaneously. Why is it that in a thunderstorm the flash is seen before the peal is heard? Can it be that when we stand at a distance the light leaves the sound behind it, as the quicker of two boys outruns the slower and arrives first at the

winning-post? Do light and sound really require time to travel from one place to another, and if so, can we not contrive means to measure the speed at which they travel? Now the objects which we have supposed to attract the boy's attention are a few of a multitude which are continually presented to us in our present state of existence, and to these objects we give the name of *Natural Phenomena.* In addition to the desire to know the character and causes of these phenomena, human beings are endowed with the power of discovering and comprehending these causes. We already know a great deal concerning all the subjects to which we have alluded, and to knowledge of this kind, when properly extended and arranged, we give the name of *Physics* or *Natural Philosophy.*

2. An acquaintance with natural philosophy is so pleasant to beings gifted with a desire for knowledge, that the subject would be pursued on this account alone, even if there existed no other motive for its cultivation. But it so happens that, by observing and reasoning upon the phenomena of nature, we become better acquainted with the forces which produce these phenomena; so that finally we are enabled to enlist these forces in our service and to make them labour for our necessities. Anybody who looks into one of our immense factories, with its multitude of wheels and spindles, where a vessel of boiling water keeps the vast machinery in incessant motion; or upon a locomotive, drawing after it with the speed of a storm a train of fifty carriages, full of passengers and merchandise, must feel the immense advantage which the world has derived from the study of the properties of steam, and of the means by which its force may be usefully applied. The electric telegraph is another example of the same kind; and although the great man who discovered that mysterious power which acts through the telegraphic wire never gained a shilling by it—never indeed entertained the idea of making it the means of sending messages across continents, or even along the bottom of the sea, in the twinkling of an eye—though his investigations were prompted by far other considerations than those

which people usually, but often thoughtlessly, call *practical*—his labours are not on this account the less a blessing to mankind.

3. General Properties of Matter.—The source of all the phenomena embraced by natural philosophy is *matter*; this is the foundation stone of our building, and we shall commence with it. Plain as the subject may appear, philosophers have disputed much regarding matter; and the probability is that every reflecting youth, after he has arrived at the years of manhood, will discover that the subject is not quite so simple as at first sight might be imagined. If a boy be asked, 'What is matter?' he will be able to show at once, by illustration, what he believes it to be. He takes up a brick or a stone and replies, 'This is matter.' He points to a tree or an animal and says, 'That is matter.' He stretches out his arm and exclaims, 'This is matter.' But if he be asked to define in words what matter is, he will not find the task an easy one. He finds, for example, that the stone which he held up as an illustration is hard, and may be tempted to say that matter is that which is hard to the touch; but a moment's reflection shows him the insufficiency of this definition; it shows him that *hardness*, as he understands the term, is not a *general property* of matter, for there are many kinds of matter, such as oil, butter, wool, &c., which are not hard. Hardness is what is called a *specific* property of matter; but it is those properties which characterize matter in general which now interest us, and some of which we will proceed to describe.

4. The first, and perhaps sufficiently distinctive, property of matter, is the ability it possesses of excluding all other bodies from the space occupied by a portion of it. This property has received the name of *impenetrability*. If you enter a dark room and stumble against a table, you are conscious of meeting something which resists your progress. You can feel round the table and thus make yourself acquainted with its *form*; but the wood of the table occupies a certain space into which your hand cannot enter. You may reply that if a nail be driven into the wood, the latter will be penetrated by the nail,

and this is perfectly correct, in the common sense of the term penetration, but not in our sense of the term. When we reflect a little it becomes evident that the nail merely *displaces* the particles of the wood; it pushes them aside, and does not by any means occupy the same portion of space that they occupy. In like manner, if you dip your hand into water, the liquid appears to be penetrated by your hand, but it is not a case of penetration in our sense of the term. If the vessel, before the immersion of the hand, be quite full of water, when your hand is introduced, a portion of liquid, exactly equal in bulk to the hand, will flow over, thus proving that the water is *displaced*, and not *penetrated*. If the liquid be contained in a cylinder, into which a piston is so tightly fitted as to render displacement impossible, when the piston is pressed down upon the liquid, its descent will be resisted with a force which is scarcely to be surmounted. If you submit air, which appears to be so easily penetrable, to the same experiment, you will find that it also possesses a power of resistance. And, although the air may be squeezed into a smaller space, this is due to the fact that the particles of air are brought, by the pressure, more closely together, and is no proof that a single particle of air and a single particle of the piston occupy one and the same space at the same time; which latter, it must be remembered, is the real meaning of penetrability.

5. Another general property, which, in connexion with the one just described, is usually deemed sufficient to characterize matter, is *extension*. But the idea of extension appears to be included in that of impenetrability; for the latter term signifies the exclusion of all other bodies from the space occupied by any one body, and the mere occupying of space is extension.

6. A third general property of matter, usually dwelt upon in works on natural philosophy, is its capability of being divided into parts. This property is called *divisibility*. A piece of chalk can be broken into two pieces; each of these two pieces can be also broken, and if we ask ourselves whether there be any end to the possibility

of breaking, we find ourselves unable to imagine any such end. We are unable to conceive of a piece of matter so small that a still smaller one is impossible. The truth of this will be at once evident on reflection, and it has led philosophers to the conclusion that matter is *infinitely* divisible; that if our senses, or our instruments, were fine enough, we might go on dividing for ever, and never come to an end.

7. A few examples, showing the minuteness of division of which matter is capable, may be here introduced. We have referred to chalk. This substance has been shown by a German philosopher named Ehrenberg to be a collection of shells. Look at a piece of chalk; you cannot see those shells, for they are too small to be seen by the naked eye, yet they exist; and, not only so, but each one of them is built up of perfect little crystals of calcareous spar, myriads of which go to form every invisible shell. But in art, as well as in nature, we have instances of the extreme divisibility of matter. It would take nearly 300,000 layers of common gold leaf, placed one above the other, to form a pile one inch in height. In certain gilding processes the layer of gold placed upon the gilt substance is so thin, that a portion of the layer whose weight does not exceed the 1,000,000,000th part of an ounce is distinctly visible to the naked eye. When a soap-bubble is distended by blowing, it becomes thinner and thinner, and finally bursts; but before it bursts a beautiful play of colours is observed upon its surface, and from these colours the great Sir Isaac Newton was enabled to determine the thickness of the bubble. He found that just before bursting, the film, at its thinnest point, was [illegible] of an inch in thickness. Oil is also capable of great distension: if the smallest drop of oil be permitted to fall upon water, in which a little caustic potash has been dissolved, it will seem to flash into colours which overspread the surface of the water; and these colours, like those of the soap-bubble, indicate that the thinness of the layer of oil is extreme. From the colours which they exhibit we also infer that the shining wings of dragon-flies and other insects are not thicker than gold-leaf. The blood of animals owes its redness to

little globules which float in a transparent liquid, called lymph; and it has been calculated that a drop of human blood, which may be suspended from the point of a fine needle, contains three millions of those red globules; while a similar drop of the blood of the musk-deer contains one hundred and twenty millions of them. Conceive a grain of sand of such a size as just to cover the dot placed over the letter *i* in these pages; there are animals so small that whole millions of them, grouped together, would not be equal in size to such a grain of sand. These are the results of microscopic research; but the microscope merely opens the door to imagination, and leaves us to conjecture forms and sizes which it cannot reveal. Turn your thoughts for an instant to the animals last mentioned—think of the apparatus by which the life of such animals is sustained: of their digestive organs—of their veins and arteries—of the little heart which impels the blood through these channels—of the globules floating in this blood—and then form, if you can, a distinct idea of the extent to which matter is actually divisible.

8. And yet, though the human mind is unable to conceive of a piece of matter so small as not to be capable of further division, it is perfectly possible that a real limit may exist to the divisibility of matter. It has been supposed that matter is composed of particles, called atoms, smaller than any that we have been considering, and so hard that it is impossible to divide them further. This opinion, or something closely resembling it, is general at the present day. A lump of copper, for example, is a collection of the atoms of copper, clinging closely together: the same may be said of a lump of gold, silver, lead, or sulphur. To such substances as are incapable of being reduced to others more simple, chemists have given the name of elements or simple bodies: there are more than sixty such elements, all the substances which we have just mentioned being examples of elementary bodies. The air we breathe is a mixture of two kinds of gas, called *oxygen* and *nitrogen*, each of these being a simple body. The word '*mixture*' is here

used intentionally, but I must now ask you to figure to your minds an atom of oxygen and an atom of nitrogen in presence of each other: under certain circumstances these atoms may be caused to unite together, so as to form a single compound atom, or molecule, as it is sometimes called: and the gas which is produced by this union is so entirely different from the mixture of oxygen and nitrogen present in the atmosphere, that the person who inhales it soon becomes intoxicated, and usually laughs immoderately: the gas receives, on this account, the name of *laughing-gas*. This example will, I trust, fix upon the mind the difference between a mere *mixture* of two simple bodies, and the compound produced by the *chemical union* of the same two bodies: in the former case the atoms of each substance are independent of those of the other; in the latter case the elements unite together, lose their individual characters, and produce an entirely new substance, this new substance being, not a simple body, but a compound one.

9. Most of the substances which we see around us are of this compound character. The water we drink is produced by the union of two other bodies, oxygen and hydrogen, although each of these bodies is a gas, and neither of them has ever been observed in the liquid condition. The salt we use at table is produced by the chemical union of a gas called chlorine with a metal called sodium, neither of which substances bears the slightest resemblance to salt.

10. Not only can one simple body combine with another, but compound bodies may also unite together to produce other bodies still more complex. There is, for example, a heavy gas which often collects at the bottom of deep wells, and sometimes kills people who enter such wells incautiously: this gas is a compound of the element *carbon* with oxygen, and is called *carbonic acid*. The lime used for building purposes is a compound of a metal called *calcium* with oxygen, the product being called *oxide of calcium*, or lime. Now the carbonic acid just referred to has the power of uniting with the lime and forming a body called *carbonate of lime*, which

is totally distinct from either. Marble is carbonate of lime; so is chalk, and so is the beautiful transparent crystal called Iceland spar. A difference in the arrangement of their particles often makes substances chemically alike exhibit totally different appearances. Sulphur, for example, may be yellow, red, or black, according to the manner in which it is prepared; but it is still sulphur. What two bodies can be more different from each other externally than the sparkling and costly diamond and a lump of dingy charcoal? Yet they are precisely the same substance, and the diamond, hard and beautiful as it is, can be burnt like a piece of coal. We might proceed further in this way, but sufficient, I think, has been said to give you some idea of the views now entertained by philosophers regarding the nature and properties of matter.

11. But there is one other property so remarkable, and so common, that I am unwilling to pass on to the next lesson without alluding to it; and that is the wonderful power which atoms and molecules possess of arranging themselves together so as to form crystals. If we examine almost any hard rock, we shall find it to be, in a great measure, composed of little crystals, which shine and sparkle in the sunlight when their clean surfaces are exposed. In this case, however, the crystals are confusedly mingled together; but under certain circumstances they grow to a large size, and thus enable us to study their exact forms and properties. Examples of quartz, or rock-crystal, as it is sometimes called, are often found weighing several pounds.

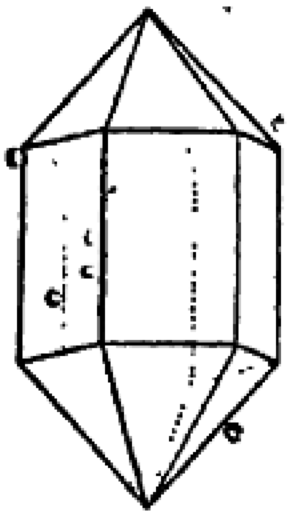

Fig. 1.

12. This crystal, which is sketched in fig. 1, consists of a column, or prism, possessing six sides, and having its two ends capped by pyramids: the crystal, however, is rarely found with both ends perfect. In all rock-crystals, no matter where they may be found, this form can be recognised. Other bodies crystallize in other forms, and sometimes the same substance possesses the power of crystallizing in two or three different forms. Sulphur is a

striking example of this. Carbonate of lime crystallizes in two forms, the crystals of one form being called arragonite, and those of the other, calcareous spar. If a piece of rock-salt be struck with a hammer, it will split freely in three different directions, which are at right angles to each other; and, however small the fragment may be, it retains this peculiarity. The substance *cleaves* into cubes, and possesses this character wherever it may be found. Calcareous spar may be similarly cloven, not however into cubes, but into figures called rhomboids. All crystals, even the hardest, are more or less cleavable. Lapidaries take advantage of this property, and instead of grinding down diamonds and other precious stones, sometimes cleave them, the surfaces exposed by cleavage being perfectly smooth and shining. If you carefully examine with your penknife a piece of sugarcandy, which is crystallized sugar, of tartaric acid, or of citric acid, you will probably find that it cleaves with facility in one direction; indeed, I cannot recommend you a more useful exercise in connexion with this portion of our subject, than the finding out of the principal cleavage of these crystals. I am sure, when you find the cleavage, you will be pleased with your discovery; and the labour spent in solving the problem will be well repaid by the superior knowledge of the structure of the crystal which you will assuredly acquire.

13. The term '*principal cleavage*' has been used, because sugar, and many other crystals, cleave less perfectly in some directions than in others. The *angles* of crystals are constant in size, but the case is different with the *surfaces;* for the circumstance of a crystal lying upon any object, say upon the bottom of a plate, during its formation, will tend to flatten the side in contact with the plate, and to make it larger than its fellows; thus figs. 2 and 3 represent

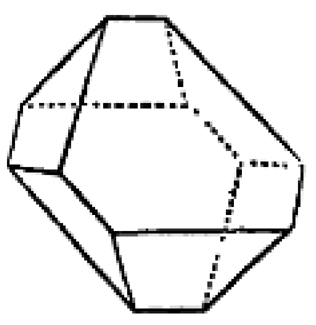

Fig 2.

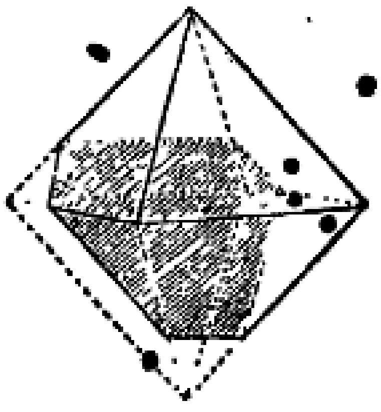

Fig 3.

different forms of crystal of the same substance as alum. Fig. 4 is a correct sketch of a group of alum crystals, obtained from a manufactory in which the substance is prepared on a large scale.

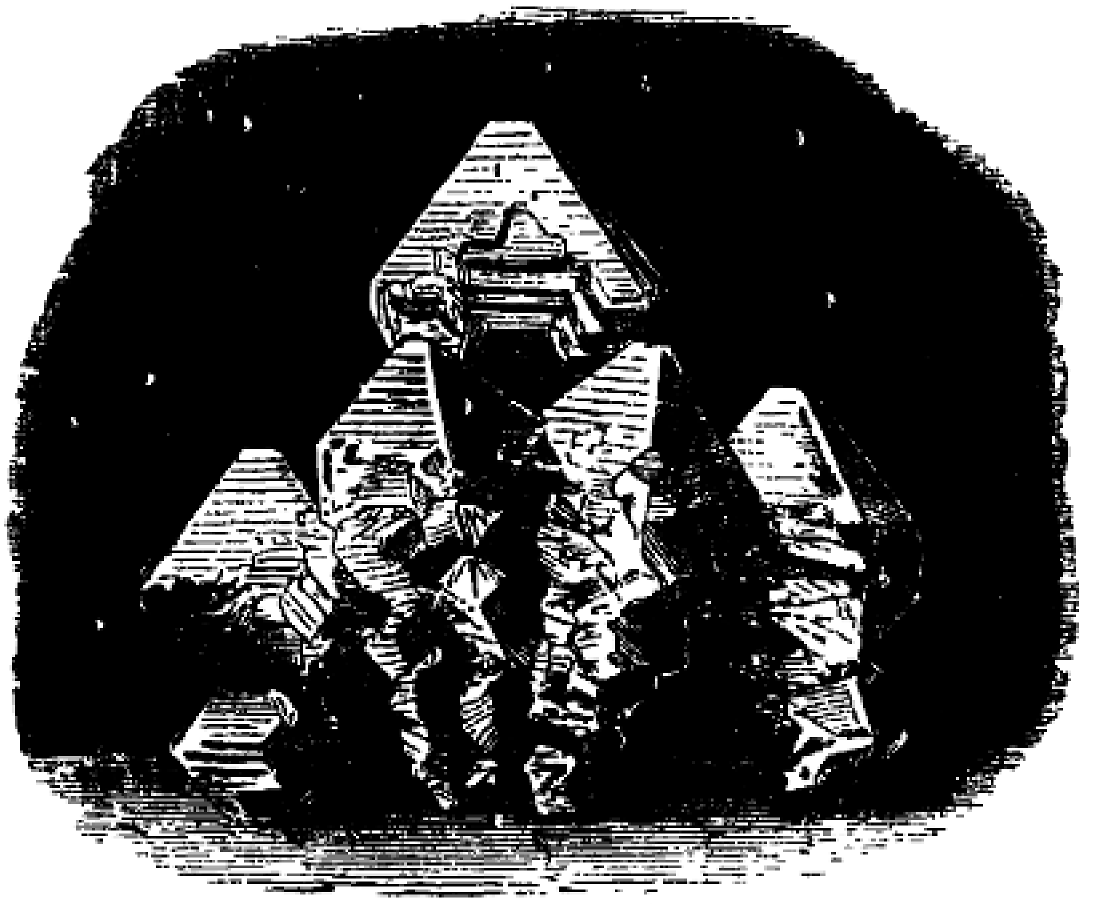

Fig. 4.

14. If you dissolve a quantity of glauber salts, or saltpetre, in water, and place the solution in a basin where it can evaporate slowly, you will soon find crystals forming round the sides of the vessel, which become larger and larger as the solution continues to evaporate. If permitted to rest against the bottom, the surfaces, as already remarked, will not be regular; but it is possible to raise a small crystal from the bottom, and to suspend it in the middle of the liquid, and by little artifices of this kind crystals may be *nursed* so as to grow to a large size and to preserve a perfect form. How then are those beautiful forms produced, whose architecture is so perfect, and whose characters are retained with such wonderful precision? Observe a bricklayer building a wall; he lays brick to brick. and the wall grows gradually larger: does it not appear as if, in the case of crystals, some invisible architect added molecule to molecule, and thus built up the

entire mass? We obtain other notions of the process, though not less calculated to excite our astonishment, if we suppose the little molecules endowed with forces which compel them to arrange themselves in a particular manner. If we imagine the bricklayer absent, and the materials with which he works endowed with the power of arranging themselves so as to form walls, houses, steeples, and monuments, the wonder would not be greater than that which actually takes place in the building of a crystal.

LESSON II.

ON FORCE AND MOTION

1. Definition of Force, &c.—Towards the conclusion of the last chapter, the word *force* was made use of, and you have a right to require of me that I should not use a term, and leave you in doubt as to the meaning of it. We have already spoken of matter, and we cannot think of force without thinking of matter at the same time. *Force is that which puts matter in motion, or which stops or changes a motion once commenced.* Forces are of different intensities or magnitudes: a stone, for example, urged with all his strength by the arm of a man, will move with greater force than the same stone when cast from the hand of a child. But, however strong the man may be, we always find that the stone he throws soon sinks to the ground; and the reason of this is, that the stone is pulled down by a power possessed by the earth, and which we call *the force of gravity.* All matter possesses this force; and it is it which, acting across the interval of ninety-five millions of miles, holds the earth as surely in her orbit as if she were connected by a chain with the sun. The same force holds all the other planets in their orbits; and it is usual to distinguish it from the force which holds the particles of substances together, and enables a body to resist being broken or torn asunder, which latter is called *the force of cohesion.*

2. We might add to our definition of force, that it *prevents* motion, as the force of cohesion does this, for

it resists the separation of a body's particles. Different bodies possess different powers of cohesion; the cohesion of chalk is far less than that of the flint embedded in it; and the cohesion of bone is greater than that of muscle. But not only do different bodies differ in this respect, but the same body may possess different powers of cohesion in different directions. Wood, for example, splits with greater ease in the direction of the fibre than in any other direction; and the cleavages of crystals, spoken of in the last chapter, also indicate that in some directions the force of cohesion is less than in others. In the direction at right angles to the fibre of wood, and to the cleavage of a crystal, the particles are held together by a comparatively feeble force. It would be well to dwell upon this for a moment, and to obtain a clear notion of the fact, that to cleave with greater ease in the direction of the fibre, the particles must be held together by a feebler force perpendicular to the fibre.

3. INACTIVITY OR INERTIA.—There is a certain quality of matter which, though properly speaking, it is not a force, may be referred to here; and that is, the tendency of matter to remain at rest, if unmoved by any external agency, and of persisting to move after it has once been set in motion. It has been asserted, that rest is natural to matter; but this is an error: matter has no more preference to rest than to motion, and is altogether incapable of moving itself, or of stopping itself when once put in motion. This property is called *inactivity* or *inertia*, which latter term has been often erroneously applied to express a tendency in matter to resist being moved, there being in reality no such tendency. It may be urged that bodies do cease moving; that the ball thrown from the hand of a cricketer, after rolling for some distance along the grass, comes finally to rest. But this stoppage of motion is not due to any power possessed by the ball to stop itself, but is simply due to the impediments presented to its progress by the grass, and the inequalities of the ground over which it rolls. Urge the same ball, with the same force, along a flagged surface, and it will

proceed much further: substitute for the flags a sheet of smooth ice, and it will proceed still further: take instead of the rough cricket-ball, a sphere of polished marble or ivory, and it will preserve its motion for a greater length of time. Thus it is seen, that in proportion as we remove impediments, the motion of the ball is prolonged; and it is fair to conclude, that if all impediments were removed, the motion would continue for ever.

4. A bullet fired from a gun enters a certain distance into wood: into mud it will enter still further: into water further still; and furthest of all into air. But even in air a great resistance is presented to the bullet; and in none of the cases mentioned have we an example of really ceaseless motion. Such examples, however, exist: there is no grass, no water, no air in the track of the earth and planets as they twirl around the sun; and the consequence is, that these bodies have continued to roll through countless ages, with the velocity which they possess to-day.

5. Illustrations of Inertia.—Many things of common occurrence are to be explained by reference to this quality of inactivity: we will here state a few of them.

When a railway train is moving, if it strike against any obstacle which arrests its motion, the passengers are thrown forward in the direction in which the train was proceeding. Such accidents often occur, on a small scale, in attaching carriages at railway stations. The reason is, that the passengers share the motion of the train, and, as matter, they tend to persist in motion. When the train is suddenly checked, this tendency exhibits itself by the falling forward referred to.

In like manner, when a train, previously at rest, is suddenly set in motion, the tendency of the passengers to remain at rest evinces itself by their falling in a direction opposed to that in which the train moves.

Matter has no power of changing the direction of its motion: on turning a corner suddenly, a horseman must lean towards the corner, in order to prevent his being thrown forward in the direction of his previous motion.

6. A rider at Astley's, standing on a horse's back, has the same motion as that of the horse which bears him; and when he jumps over a garter, or through a ring, he does not jump forward, although he appears to do so. He jumps straight upward, and the motion which he has already acquired carries him over the garter or through the ring.

If a cannon-ball be taken to the top of the mast of a swiftly-sailing ship, and let fall downwards, it might be imagined, that on account of the movement of the vessel, the ball would reach the deck at some distance *behind* the bottom of the mast; but this is not the case. Before the ball was released it partook of the motion of the ship, and allowance being made for the resistance of the air, this motion is retained by the ball, and prevents it from being left behind by the mast.

7. Nay, if we suppose the ship sailing from west to east, the ball, strictly speaking, will fall a little *in advance* of the mast. This is rather a difficult point, but I do not despair of making it clear. The earth performs a complete revolution from west to east, upon its axis, once in 24 hours; and hence, every point upon the earth's surface, with the exception of the two poles, must describe a circle daily. If you fix your eye upon any point on a globe, and turn the globe, you will see instantly what is meant: the point goes round in a circle. The circumference of the earth at the equator is 24,000 miles; and, therefore, a stone or other object at the equator, describing, as it does, a circle of the magnitude just mentioned, must move with a velocity of 1000 miles an hour. A point in England, however, moves with much less speed, because the circles described become smaller and smaller as we approach the poles; and there is no difficulty in understanding that the larger the circle described in the 24 hours, the greater must be the velocity of the point which describes it. But it is evident that the top of St. Paul's, or of Salisbury spire, or of the mast of a ship, or the summit of any other high object, describes, as the earth rotates, a larger circle than the bottom of the same object; and for this reason, a body placed at the top will move

with a greater velocity than at the bottom. Hence, when a ship sails from west to east, a ball at the mast-head will, on account of the earth's rotation, move more quickly in an easterly direction, than the bottom of the mast; and retaining this superiority of motion after it is released, it must fall in advance of the mast instead of behind it. It will, probably, require a little time to familiarize the mind with this reasoning; but the time thus employed will be well bestowed. I cannot, indeed, recommend too strongly to boys, when studying natural philosophy, the practice of pondering upon subjects which at first sight may appear difficult; it is really wonderful what patience can accomplish here; and there is no delight equal to that experienced by a boy when he finds his perseverance rewarded by the conquest of a difficulty.

8. Let us now return to the study of force.

If a ball of light wood be let fall from a table upon a foot underneath, very little injury, if any, will be done to the foot; but if the ball be of lead, or of any other heavy substance, it may bruise the foot and cause considerable pain. It is evident that, in this case, the increase of pain is due to the increase of force with which the heavy body strikes the foot, or that the force increases as the weight increases.

A bullet projected from a musket barrel will pass through a board an inch in thickness, whereas a similar bullet cast from the hand will make but a slight impression on the board. What is the cause of the difference of force here exhibited? Not a difference of weight, as in the case last supposed, but a difference of *velocity*. The bullet issuing from the musket travels at a much greater speed than that cast from the hand, and hence it is that its force is so much greater.

9. In estimating the force of a moving body, therefore, two things are to be taken into account; the *mass* moved and the *velocity* with which it moves.

The following table, in which the velocities of various objects are stated, may be useful for reference.

10. The Romans and other ancient nations were accustomed to batter down the walls of the cities which they

Moving Objects.	Miles per hour.	Feet per second.
Man walking	3	4½
Horse trotting	7	10½
Swiftest racehorse	60	90
Railway train (English)	32	48
„ (American)	18	24
„ (Belgian)	25	37½
„ (French)	27	40½
„ (German)	24	36
Swift English steamboats navigating the Channel	14	21
Swift steamers on the Hudson	18	27
Fast-sailing vessels	10	15
Current of slow rivers	3	4½
„ rapid rivers	7	10½
Moderate wind	7	10½
A storm	36	54
A hurricane	80	120
Air rushing into vacuum	850	1275
Common musket-ball	850	1275
Rifle-ball	1000	1500
24-lb. cannon ball	1600	2400
Bullet discharged from air-gun, air being compressed to 100th of its volume	466	700
Sound through air at temp. 32° Fahr.	726	1089
„ „ 60° Fahr.	747	1120
Earth moving round the sun	67,374	101,061
A point on the earth's surface at equator, in consequence of diurnal rotation	1037	1555

attacked by means of heavy instruments called battering rams. It was by means of such instruments that breaches were made in the walls of Jerusalem, by the soldiers of the Roman Emperor Vespasian. But a glance at the foregoing table will be sufficient to show us why these unwieldy instruments have, in modern warfare, been quite superseded by cannon-balls. The possession of gunpowder enables us to impart a velocity of 2,400 feet a second to a 24-lb. cannon-ball; and this enormous velocity is more than sufficient to counterbalance the superior weight of the ram, and to convert the ball into a far more formidable implement of destruction.

11. Comparison of Forces.—We have thus far contented ourselves with showing that the greater the weight, or the greater the velocity, the greater will be the force; but we must now be a little more precise, and endeavour to compare two forces together, so as to obtain an exact notion of their relative magnitudes. It requires a certain amount of force to make a body, weighing 5 lbs., move at the rate of 20 feet a second, and it is perfectly evident that it would require a greater exertion of force to make a weight of 10 lbs. move with the same velocity. If we suppose a mass of 10 lbs. cut into two equal portions, the force first mentioned will be able to cause either of these 5 lb. masses to move at the rate of 20 feet a second, and if the said force be exerted *twice*, it will cause *both* the masses to move at the same rate. Hence we may infer that to cause a body weighing 10 lbs. to move through 20 feet a second, twice the quantity of force must be expended that is necessary to cause a weight of 5 lbs. to move through the same space, or, to speak more generally, the force of the moving body is proportional to its weight.

12. It is also found that the forces of two bodies of the same weight, but moving with different velocities, are proportional to the velocities; so that if one body move twice as fast as the other, it will possess twice the moving force, and if it move ten times as fast as the other, it will possess ten times the moving force.

13. But when the bodies differ both in weight and velocity, in the comparison of their forces, we must take both into account. Imagine a weight of 5 lbs. moving with a velocity of 10 feet a second; if we double the velocity, we double the force,—that is to say, a weight of 5 lbs., moving at the rate of 20 feet a second, possesses twice the force of the same weight moving through 10 feet a second.

But a weight of 10 lbs. moving through 20 feet a second possesses twice the force of a weight of 5 lbs. moving at the same speed. Hence a weight of 10 lbs. moving through 20 feet a second possesses *four times* the force of a weight of 5 lbs. moving through 10 feet a second: this shows us that if we double the weight and double the velocity we increase the force four times. A similar reasoning would show us that, if we trebled the weight and trebled the velocity, the force would be increased *nine* times; also, that if we trebled the weight and doubled the velocity, the force would increase six times; or, in other words, *that the force increases as the product of the weight and velocity increases.*

14. Indeed the product of the mass into the velocity is always taken as the expression of the force: our weight of 5 lbs. for example, moving through 10 feet a second would have a force of

$$5 \times 10 = 50,$$

and our weight of 10 lbs. moving through 20 feet a second would have a force of

$$10 \times 20 = 200,$$

and we see that the numbers 50 and 200, which express the forces, are in the ratio of 1 to 4, which is the same result as that proved above. If, therefore, we denote the mass of a body by the letter M, and its velocity by V, the force will be

$$M \times V.$$

This product is usually called the *momentum*, or *moving force* of the body.

For the sake of imprinting this simple principle upon the mind, we will give a few examples of its application.

Example 1.—A ball weighing 9 lbs. moves with a velocity of 25 feet a second; it is required to compare its momentum with that of a 5-lb. ball moving at a speed of 45 feet a second?

Here we have $9 \times 25 = 225$.
And $5 \times 45 = 225$.

The products are equal, and hence we conclude that the momenta, or moving forces, of the two bodies are equal also.

Example 2.—A battering ram, weighing 5,300 lbs., was propelled with a velocity of 7 feet a second, it is required to compare its momentum with that of a 30 lb. cannon-ball moving at the rate of 2,492 feet in a second? By proceeding in the manner indicated it will be found that the momentum of the ball is about twice that of the ram.

15. It is evident that if of the three quantities, weight, velocity, and momentum, any two be given, the third may be found.

(1.) If the weight and velocity be given, we multiply them together to obtain the momentum.

(2.) If the momentum and velocity be given, we divide the momentum by the velocity to find the weight.

(3.) If the momentum and weight be given, we divide the momentum by the weight and obtain the velocity.

Example 3.—The weight of a body is 52, its momentum is 468, required its velocity?

$$468 \div 52 = 9 \text{ Answer.}$$

Example 4.—The velocity of a body is 15, its momentum is 180, required its weight?

$$180 \div 15 = 12 \text{ Answer.}$$

16. In all these cases we have only to be careful, that when we compare the forces of two moving bodies we must have their weights expressed in the *same unit*, and also their velocities expressed in the same unit. The unit of weight may be an ounce, or a pound, or a ton; and the velocity may be either so many feet in a second or miles in an hour; but if the foot be taken as the unit of space and the second as the unit of time, in one case, the same units must be taken in the other. In the next lesson we shall have occasion to apply some of the simple principles established in the present one.

LESSON III.

COLLISION OF BODIES.

1. **Definition of Elasticity and Hardness.**—Before we enter upon the subject of the present lesson it is essential to obtain perfectly clear notions of what is intended to be expressed by the words *elasticity* and *hardness*. If a strip of India-rubber be drawn out, and then liberated, it will return to nearly the shape which it possessed before being stretched: in this case a force appears to reside in the particles of the rubber, which is capable of restoring the shape of the piece, and to this force we give the name of elasticity.

In like manner if we take a rod of glass and bend it, when the *deflecting* or bending force is removed, the glass returns almost completely to its former position. If the same rod be softened by heat, and drawn out to a thickness not greater than that of a human hair, when cool it may be twisted; but when the force of twisting, or *torsion*, as it is called, is removed, the glass thread untwists itself, and the force which enables the glass to do this we call elasticity. Glass, indeed, is a very elastic substance, and I choose it, as an example, to show that great elasticity and great *brittleness* may exist together, in one and the same body.

Ivory is also a very elastic substance. If we permit an ivory ball to fall from a certain height upon a flat unyielding surface, the ball after it meets the surface will become flattened as represented in fig. 1, the force which the ball has acquired during its descent being all expended in compressing it. But the ball will not remain compressed, the particles which for a time had been forcibly brought closer together along the diameter A B, now make an effort to push themselves asunder; the ball recoils against the surface, and this back-push causes it to return along the path through which it had descended. If the force with which the particles push themselves asunder be equal in all respects to the force which had pressed them together, the ball is said to be *perfectly elastic*, and it will ascend to the same point from which it fell; but if this be not the case the ball is said to be *imperfectly elastic*.

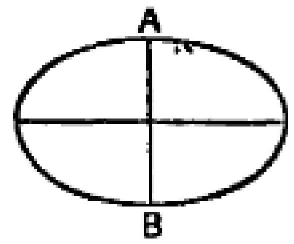

Fig. 1.

2. If after the shape of a body has been changed by any external force the new shape be retained, without any alteration, when the external force ceases to act, such a body is said to be *perfectly inelastic*: butter and soft clay approach to this condition, for if a lump of either of these substances be squeezed, or let fall upon the ground, it becomes flattened and *remains so;* but we are acquainted with no body in which elasticity is entirely absent, though many bodies possess it in a very

low degree; nor is there any body in which elasticity is perfect.

3. Elasticity then is a force, within a body, which tends to restore the shape which had been changed by a force without it. The property of *hardness* consists in the resistance to change of shape; and a body whose particles do not yield in the slightest degree to any external force applied to it, is said to be *perfectly hard.* Let us now inquire what will take place when a perfectly hard ball is permitted to fall upon a perfectly unyielding surface. Casting an eye upon fig. 1, we see that the rebounding of the ivory ball is solely due to the effort it makes to recover its shape; but, in the case of the perfectly hard ball, there is no change of shape, and consequently, no such effort. Hence it is evident that the hard ball will have its motion suddenly arrested by the surface, and will remain in contact with it, without rebounding.

We are now prepared to enter upon the subject intimated by the title of this lesson, and we will commence with the collision of such bodies as are assumed to be perfectly hard; for although this assumption is not strictly true, there being in reality no such thing as a perfectly hard body, as we have defined it; still the assumption will simplify our calculations very much, and where a practical object is sought, proper allowance for imperfect hardness can be made afterwards.

4. We will also suppose the balls we operate with to be *homogeneous,* that is to say, one part of the same ball must not be heavier than another; and we will further assume that when one ball approaches another, the direction of its motion is along the line which joins the centres of the balls, as shown in fig. 2: collision which takes place in this way, where the balls do not strike each other obliquely, is called *direct impact.*

Fig. 2.

5. First, then, we will consider the case of two perfectly hard balls of the same weight and possessing

the same velocity, moving towards each other in *opposite directions.* It is evident, that, inasmuch as the forces with which the balls move are equal and opposite, the motion of both balls will be destroyed by collision, and they will come perfectly to rest, as shown in fig. 3.

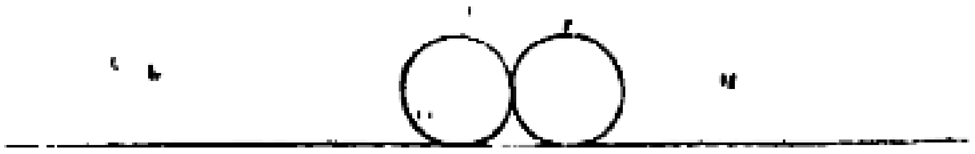

Fig. 3.

6. We will now vary the question, and suppose that the balls are not of the same weight, and do not move with the same velocity. Suppose, for example, that one of them weighs 9 ounces, and moves at the rate of 15 feet a second, while the other weighs 12 ounces, and moves, in the opposite direction, at the rate of 10 feet a second,—what will be the state of things after collision?

It is evident here that if the forces or momenta with which the balls move be not perfectly equal, the motion will not be completely destroyed when they strike against each other. The two balls will move together *as one mass* in the direction of that ball whose moving force is greatest. As explained in the last lesson, the moving force of each ball is found by multiplying its weight by its velocity; hence

9 × 15 = 135 momentum of smaller ball.
12 × 10 = 120 momentum of larger ball.

Now, as the momentum of the smaller ball is the greater of the two, it is evident that both balls will move together as a single mass in the direction of the smaller ball. These considerations will prepare us for a few examples, which will serve to illustrate this interesting subject.

Example 1.—A ball A, moving at the rate of 25 feet a second, is followed by another, B, moving at the rate of 35 feet a second, the weight of the former ball is 12 lbs., and of the latter 8 lbs.; required the *common velocity* of the two balls after direct impact.

The first step, as before, is to find the momenta of the two balls.

12 × 25 = 300 momentum of A.
8 × 35 = 280 momentum of B.

Now I have reserved a statement to be made at this particular place, where it is essential to our progress, hoping thereby to imprint it more firmly upon the memory;—it is this—in the case before us *there is no force lost.* When the balls strike together, the quick ball imparts a portion of its motion to the slow one; but the *force* of the two balls after impact, and when they move together as a single mass, is precisely equal to the sum of the forces which they possessed before impact: let us add these two forces together;

$$300 + 280 = 580$$

This, then, is the momentum of a mass which is made up of the two balls,—or, in other words, which weighs $12 + 8 = 20$ lbs., and our question resolves itself into this:—Given the weight 20, and the momentum 580, to find the velocity. According to the process explained in the last lesson, we obtain the velocity by dividing the momentum by the weight; hence,

$$580 \div 20 = 29,$$

the common velocity after impact is, therefore, 29 feet a second.

7. If it be required to know the velocity lost by B and gained by A, we should find the former by subtracting 29, the velocity of B after impact, from 35, the velocity before impact, the velocity lost being 6 feet a second. By deducting 25, A's velocity before impact from 29, its velocity after impact, we obtain for A's gain 4 feet a second.

8. We can here subject our calculation to proof; for if what we have stated be correct, the *force* gained by A ought to be exactly equal to that lost by B; now the force gained by A is found by multiplying A's weight by the velocity which it has gained, or,

$$12 \times 4 = 48 \text{ A's gain of force.}$$

By a similar process, the loss of B is found to be

$$8 \times 6 = 48,$$

which shows that the force lost by one ball is precisely equal to the force gained by the other.

I trust you will study this example until it is perfectly plain to you; for if you succeed in obtaining a clear notion of every example as we proceed, each subsequent one will be a source of new interest and pleasure; while there is nothing but dissatisfaction and unhappiness experienced when a boy passes impatiently to a new portion of his task, without having endeavoured to master the previous ones.

Example 2.—Suppose the same two balls as those introduced in the last question to move in opposite directions, instead of in the same direction, required the common velocity of the two balls after collision.

Now it is evident that if the balls moved with precisely equal forces, they would completely neutralize each other's motion by collision, and come to a perfect rest. Suppose the force on each side to be 300, we should, in the case of the balls moving in *the same direction*, find the combined force, after collision, to be $300 + 300 = 600$; but if they moved in *opposite* directions, we should find the force after collision to be $300 - 300 = 0$; the force producing visible motion would completely disappear, and rest would be the consequence. But, in the present instance, the forces do not completely neutralize each other, but a balance of

$$300 - 280 = 20$$

remains in favour of the ball A. The two balls, after impact, will therefore move with a force of 20 in A's direction; and the question now is;—given the weight, $12 + 8$ or 20, and the momentum 20, to find the velocity: dividing, as before, the momentum by the weight, the velocity is found to be 1 foot per second.

Example 3.—A ball, A, weighing 32 lbs., and moving with a velocity of 26 feet a second, follows another ball, B, the weight of which is unknown, but which moves at the rate of 12 feet a second; the common velocity after impact is found to be 20 feet a second; it is required from this to find the weight of the ball B.

We will here show how the principles of algebra may be applied to the solution of questions like the present:—

Let $x =$ the weight of B in lbs.;

then we have

$$32 \times 26 = 832 \text{ A's momentum,}$$
$$x \times 12 = 12x, \text{ B's momentum;}$$

adding both momenta together, and dividing the sum by the weight of the two balls, we have

$$\frac{832 + 12x}{32 + x} = 20 \text{ the common velocity.}$$

Clearing of fractions, we have

$$832 + 12x = 640 + 20x$$
$$8x = 832 - 640 = 192,$$

or $x = 24$ the weight sought.

But for the sake of those unacquainted with algebra, we will solve the question differently. It may, however, be remarked, that a knowledge of algebra increases our power immensely in dealing with mechanical questions; and, in difficult cases, it is altogether indispensable.

The question before us enables us at once to find the velocity which A loses and which B gains by the collision; the former is evidently 6 feet a second, and the latter 8. We can also, by multiplying A's weight by its loss of velocity, find the *momentum* lost by A;—it is

$$32 \times 6 = 192.$$

Now this must be equal to the *momentum gained* by B, and the question therefore is;—given the gain of B in velocity 8, and in momentum 192; required the weight of B; we obtain it, as before, by dividing the momentum by the velocity,—

$$192 \div 8 = 24 \text{ the weight sought.}$$

9. A great number of interesting and pleasant questions might be proposed in connexion with this subject; and if the pupil understand the foregoing thoroughly, he will have no difficulty in imagining and exercising himself with others.

10. **Distinction between Elastic and Inelastic Collision.**—In the collision of perfectly hard bodies a certain amount of force is expended in communicating *momentum* from one body to another; and during this act the particles of the bodies are supposed not to yield in the slightest degree to the force of compression. But in the case now to be considered, the bodies are compressed during the communication of momentum, but they do not remain compressed; they instantly expand again

with precisely the same force as that with which they were squeezed together, and the consequence is that in the collision of perfectly elastic bodies the gain or loss of velocity is exactly *twice* what it is when the bodies are perfectly hard.

11. When two equal and perfectly hard balls, moving with the same velocity, but in opposite directions, strike together, they come to rest after collision without change of shape, as in fig. 4.

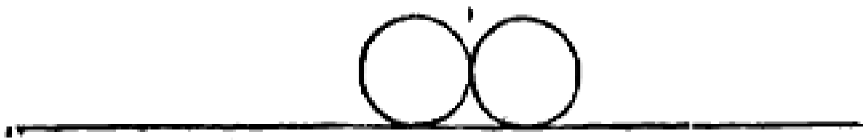

Fig. 4.

But if the balls be perfectly elastic they do not act in this way; both are flattened during the act of compression, as in fig. 5.

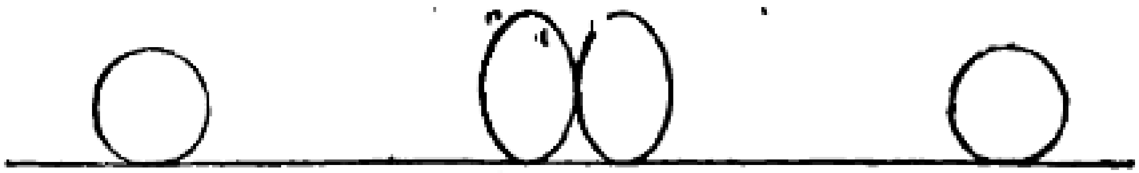

Fig. 5.

But when the flattening has attained its utmost limit, a mutual *push* is exerted by the two balls, which causes them to fly asunder with the same velocity as that with which they approached each other before impact. If, for example, each ball possessed a velocity of 9 feet a second before impact, this velocity is not only destroyed in each case, but it is converted into one in the opposite direction; and in this case it is usual to say that the loss of velocity is doubled. I know that this will appear a new notion of loss to many boys, inasmuch as the *absolute velocities* after impact are the same as before. The case may be illustrated by a parliamentary candidate who reckons on the support of a certain voter: if the voter dies, the candidate may be said to lose a vote; but if the voter change his opinion, as our ball has changed its direction, and votes for the opposition candidate, then the loss may be said to be doubled.

12. In the case of elastic collision, we cannot speak of the *common velocity* after impact, but the gain or loss of each ball must be determined separately.

Example 1. Two perfectly elastic balls, A and B, each weighing 8 ounces, move in the same direction; B moves with a velocity of 10 feet a second, and is followed by A at a speed of 15 feet a second: required the velocity of the two balls after direct impact.

Supposing A and B to be perfectly hard, the loss of A and the gain of B is found, in the manner already described, to be each $2\frac{1}{2}$ feet per second; but in the case of elastic collision, the loss and gain are doubled, hence A's loss will be 5 feet, and B's gain an equal quantity. Deducting, therefore, 5 from A's velocity, and adding 5 to B's, we find the velocities after impact to be 10 and 15.

13. This result is worth bearing in mind, for it shows us that A's velocity after impact is the same as B's before impact, and that B's velocity after impact is the same as A's before impact. This holds good in all cases where the elastic bodies are equal, and move before impact in the same direction. *Two such bodies exchange velocities by collision.*

Example 2. A ball, A, of 9 lbs., moving with a velocity of 62 feet a second, strikes or impinges upon a ball, B, at rest, and possessing the same weight as A: required the gain and loss of velocity by collision.

Here we have the momentum of A before impact,

$$62 \times 9 = 558;$$

and, inasmuch as B has no moving force before impact, this must be the *momentum of the two balls* after impact. Hence, supposing the balls to be perfectly hard, we should find the velocity after impact to be—

$$\frac{558}{18} = 31.$$

If we deduct this from A's velocity before impact, and add it to B's, we should find the loss of the former 31, and the gain of the latter the same quantity. But as the balls are perfectly elastic, this gain and loss must be doubled; that is, A's loss is 62, and B's gain is 62. But if A's loss be 62, it has no velocity remaining, for its velocity before impact was only 62; and thus we arrive at the remarkable result, that if *an elastic body in* *motion strike another equal elastic body at rest, the moving body communicates all its motion to the other, and comes itself to rest.*

14. This result enables us to explain an experiment often made with a row of ivory balls, all of the same size, as in fig. 6.

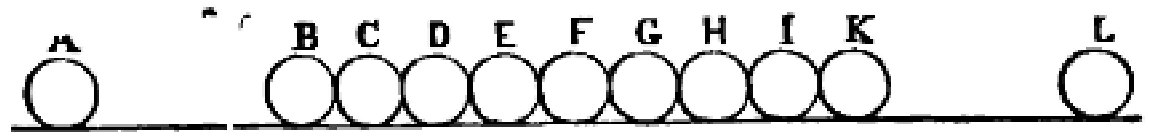

Fig. 6.

If the ball A be caused to strike the end ball B, it communicates its motion to B, and comes to rest itself; B communicates its motion to C, and comes to rest; C communicates its motion to D; D to E, and so on to K; K communicates its motion to L, which starts forward. If the balls were perfectly elastic, the velocity of L would be precisely equal to that of A at the commencement.

Example 2. A, weighing 30 lbs, and moving at 26 feet a second, impinges on B, weighing 28 lbs., and at rest: required the loss and gain of velocity by collision.

Treating them as perfectly hard balls, we should find the common velocity after impact to be $13\frac{13}{29}$; this would express B's gain, and deducted from 26 it would give $12\frac{16}{29}$ as A's loss; doubling these numbers we find the loss and gain when A and B are perfectly elastic.

Loss $25\frac{3}{29}$.
Gain $26\frac{26}{29}$.

By comparing A's loss with A's original velocity, we see that the latter is not quite destroyed; in the question we have supposed A a little greater than B; and *where the impinging body is greater than the body at rest, the motion of the former, after impact, is always in the same direction as its motion before impact.*

Example 3. A, weighing 8 lbs., and moving at 12 feet a second, impinges on B, weighing 9 lbs., and at rest: required the loss and gain by collision.

Supposing the balls to be hard, the common velocity after impact would be $5\frac{11}{17}$; hence A's loss and B's gain would each be equal to $6\frac{6}{17}$; doubling this we have the gain and loss for perfectly-elastic balls equal to $12\frac{12}{17}$. If we compare A's loss thus found with its velocity before impact we see that the former actually exceeds the latter. The velocity before impact is 12, the loss is $12\frac{12}{17}$; this indicates that not only is A's velocity, in its first direction, all destroyed, but that it is partly converted into a motion in the *opposite* direction. This result is also general. If, in elastic collision, the impinging body be *less* than the body at rest, the former is *reflected back* by the collision.

15. To sum up:—

(1.) When both bodies are *equal*, the impinging body yields up all its velocity and comes to rest itself.

(2.) When the impinging body is *greatest*, its motion after impact is in the same direction as before.

(3.) When the impinging body is *least*, it is reflected back, along its former path, by the act of collision.

LESSON IV.

ON TERRESTRIAL GRAVITY.

1. **Gravity**, as before explained, is that force by which matter attracts matter. If with two long strings two ivory balls were suspended from two pins, as in fig. 1, we should find, if our means of measurement were fine enough, that the two balls had approached each other, through the exercise of the mutual attraction subsisting between them. The attraction of a suspended ball by a mountain has, indeed, been accurately measured. Very exact experiments have also been made to determine the attraction of a small ball by a very large and heavy one. A beam was suspended horizontally from its centre by a fine wire, and, at each end, a ball was fixed; near each ball a much larger one of lead was placed as in fig. 2; and by a proper mode of observation, the exact amount of the twisting endured by the wire, in consequence of the attraction, was ascertained. Such ex-

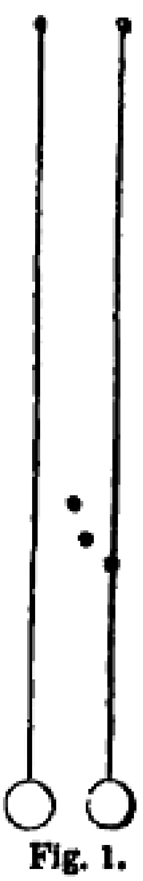
Fig. 1.

periments were made for the purpose of ascertaining the *density* of the earth, and it was thus found that its density is about five and a half times that of water; that is to say, our world weighs as much, or contains as much matter, as five worlds and a half of equal size, and formed of common water. Such experiments incontestably prove that the attraction of gravity is not confined to the earth as a whole, but is exercised by all its parts. And be it remembered, that when we see a stone falling to the earth, that it is not the earth alone which is the attracting body; the stone also attracts the earth, but, on account of the immense mass of the latter, its motion *towards the stone* is so small as to be incapable of observation or measurement.*

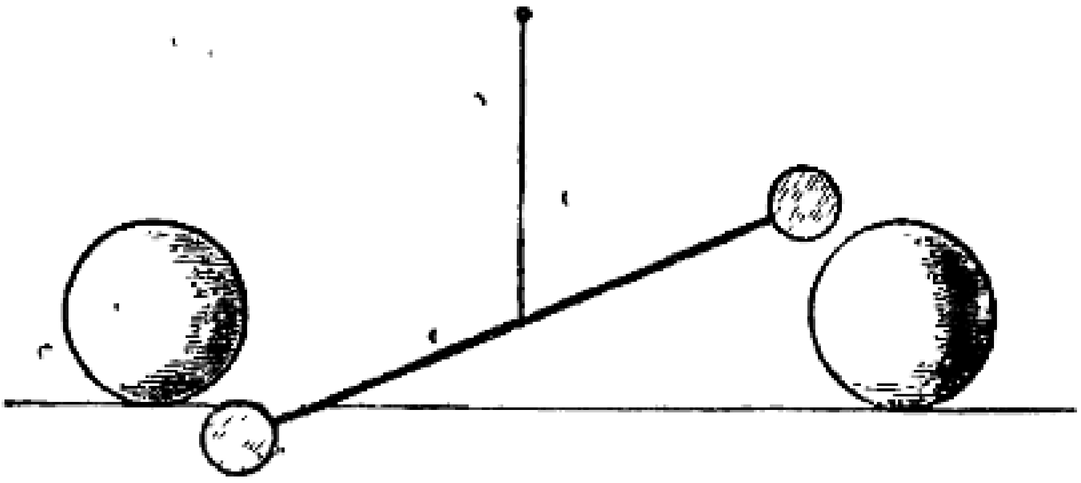

Fig. 2.

2. In considering the motion of any body, three things are to be taken into account: 1st, the *space*, over which the body moves; 2nd, the *time* of its motion; 3rd, the *velocity* with which it moves.

3. When the motion of the body is such that it passes over equal distances in equal times, the body is said to move with a *uniform* velocity. If, for example, we possessed a surface perfectly smooth and horizontal, and also a ball perfectly smooth, such a ball upon such a surface, when once set in motion by a single stroke, would, as already explained, continue to

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* Experiments have been made quite recently by the Astronomer Royal to determine the density of the earth. His method is to observe the difference between the rate of vibration of a pendulum at the top and the bottom of the shaft of a deep mine. The calculations are not yet quite finished, but they will probably show the earth to be a little more than six times the density of water.

move without alteration of velocity. In this case, the force acting upon the ball, is what is called an *instantaneous* or *impulsive* force; it consists of a shock, the motion impressed by the shock being retained by the ball without increase or diminution. The ball moves with a *uniform* velocity.

4. But the action of terrestrial gravity is not an action of this kind; it does not impart a shock and then cease: it is a *continuous* force, and not an instantaneous one. If a stone be let fall from the top of a high tower, gravity acts upon it during the whole course of its descent, and the consequence is that the stone moves quicker and quicker the longer it is in motion:—it moves with an *accelerated* velocity.

In like manner, if the stone be projected upwards, its ascent is opposed by gravity; in consequence of this it moves slower and slower, and finally ceases to ascend; —it moves with a *retarded* velocity.

5. In the case of uniform motion, if the velocity of a moving body, and the time of its motion be given, the *space* over which the body has moved will be found by multiplying the velocity by the time. Thus, supposing a body to move at the rate of ten feet a second, and that it had been in motion for seven seconds, the space over which it has passed will be

$$10 \times 7 = 70 \text{ feet.}$$

It is also plain, that if the space and the velocity be given, the *time* of the body's motion will be found by dividing the space by the velocity. Thus, supposing the space through which a body has moved to be seventy feet, and its velocity ten feet per second, then the time of its motion has been

$$70 \div 10 = 7 \text{ seconds.}$$

And if the space and the time be given, the *velocity* is found by dividing the space by the time. Thus, if a body has moved through the space of seventy feet, and been seven seconds in motion, its velocity has been

$$70 \div 7 = 10 \text{ feet per second.}$$

6. To sum up:—it is plain that if of the three quantities, *space*, *time*, and *velocity*, any two be given, then in the case of uniform motion, the third may easily be found.

7. **Investigation of the Laws of Falling Bodies.**—It is probably needless for me to tell the reader of this book what a *rectangle* is; that it is a four-sided figure, whose angles are all right angles, shaped, for example, like a school slate; and that the *area* is found by multiplying the length of the rectangle by its breadth.

8. Now, in the case of uniform motion, if we suppose the *velocity* to be represented by one side of a rectangle, and the *time* of motion by another, the *space* through which the body has passed, will be represented by the area of the rectangle.

Supposing, for example, in fig. 3, A B to represent the velocity 10, and B C the time of motion 5; then it is evident that the product of 10 and 5, which is the area of the rectangle, will also denote the space through which the body has passed.

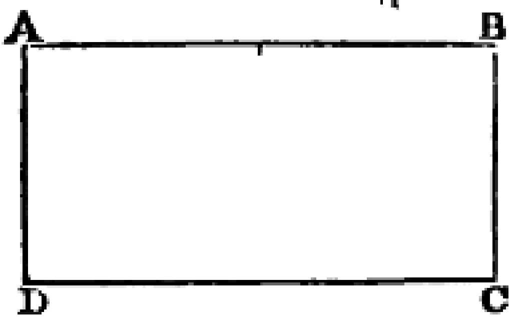


Fig. 3.

Supposing, however, that after the body has been 5 seconds in motion, it receives a shock which increases its velocity from 10 feet a second to 15 feet a second; and that it moves uniformly with this newly-acquired velocity for the next 5 seconds, at the end of which it receives another shock, which increases its velocity from 15 to 20 feet a second, moving uniformly with this new velocity for the succeeding 5 seconds; supposing a motion of this kind to continue, suddenly increasing at the end of each 5 seconds, by the same fixed quantity, 5 feet, it is evident that the entire space passed over, in this case will not be represented by a single rectangle, but by a series of them. Thus, let A B, fig. 4, represent the velocity at the commencement, the rectangle A B C D will represent the space passed over in the first 5 seconds; the velocity then becomes greater, and must be represented by a longer line D E; the space passed over in the next 15 seconds will be represented by the rectangle D E F G: in like manner, the space passed over in the third period of 5 seconds will be represented by the rectangle F H I K; in the fourth period by the rectangle I L M N: the entire space passed over in the whole 20 seconds will therefore be represented by the figure A M N L H E B.

9. We will now suppose the velocity at the commencement to be much smaller than 10 feet ~~a second~~, and will therefore represent it by a much shorter line; and also that the accessions, or increments of velocity, take place at shorter intervals—say at intervals of a second—these increments being proportionately smaller than in the former case. It is evident, that, proceeding as before, we should find the whole space passed over to be represented by the area of such a figure as A B M N, fig. 5.

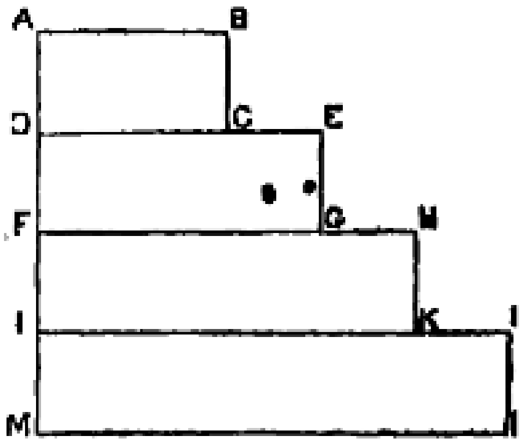


Fig. 4.

Now, it is plain that this figure approaches much nearer to the shape of a right-angled triangle than the last one; and a little reflection will render it evident that if we make the commencing velocity still smaller, and suppose the increments to follow each other more quickly, that we should obtain a still closer approximation to a triangle.

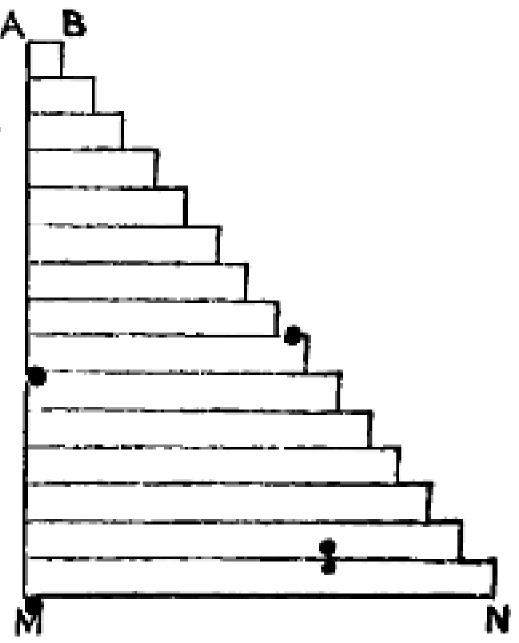


Fig. 5.

10. If, for example, the commencing velocity were almost nothing, the length of A B would be almost nothing also; and if the commencing velocity were really nothing, A B would lose all length, and dwindle to a mere point, A, fig. 6. And supposing the increments of velocity to take place in the thousandth or millionth part of a second, instead of a whole second, it is plain that the stair-like appearance between B and N (fig. 5) would almost wholly disappear. And if the little shocks which produce the increments of velocity take place instantly one after the other, so as to melt into a

continuous *pull*, the steps would vanish altogether, and the whole space passed over would be represented by the right-angled triangle A M N (fig. 6.)

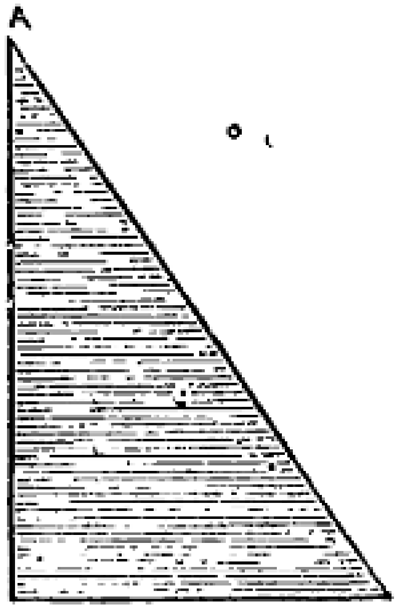


Fig. 6.

11. Now, if we suppose a body to be let fall from a state of rest, and drawn to the earth by gravity, it is exactly in the condition which we have last supposed: the commencing velocity is nothing, and the force acting upon it is a continuous and constant pull; hence the whole space passed over by a falling body is accurately represented by the area of a right-angled triangle. The establishment of this principle places it in our power to solve a great number of interesting questions relating to terrestrial gravity.

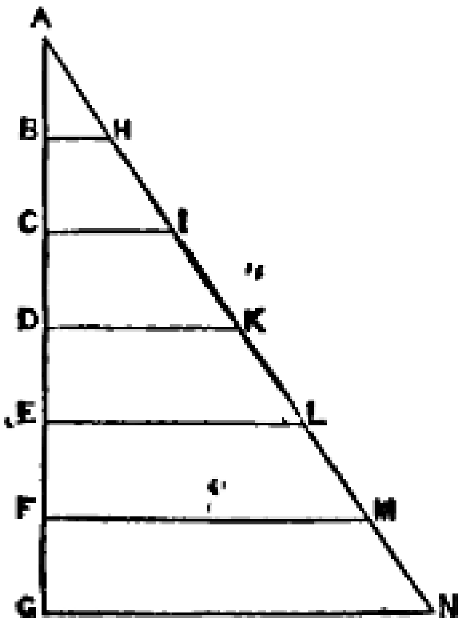


Fig. 7.

12. Let the line A G, fig. 7, represent the *time* of a body's fall, and let this line be divided into equal parts, A B, B C, C D, D E, E F, F G, which shall express the seconds of the body's fall; the horizontal lines will then represent the *velocity* of the body at the corresponding times. The line B H expresses the velocity at the end of the 1st second; C I the velocity at the end of the 2nd second; and so on to G N, which expresses the velocity at the end of the 6th second. The little triangle, A B H, will then represent the space passed over in the 1st second; the four-sided figure, B C I H, will represent the space passed over in the 2nd second; and each of the succeeding four-sided figures will represent the space passed over in the single second to which it corresponds; the figure F M G N thus representing the space passed over in the 6th second.

13. I must here caution you against confounding the

space passed over in the 6th second with the space passed over in 6 seconds. The latter space is evidently formed by adding all the spaces passed over in the 6 single seconds together; in other words, the space passed over in 6 seconds is represented by the triangle A G N.

14. RELATION OF TIME AND SPACE.—We will now compare the spaces passed over in the single seconds with each other; and to render the process more simple, we will at present confine our selves to the first two seconds. Draw the line H O, fig. 8, parallel to A C, and join the points B O. It is perfectly evident that the triangle B H O is equal to the triangle H O I, and also equal to B C O; or, in other words, the three triangles into which the second space is divided are equal to each other. It is just as plain that the triangle B H O is equal to A B H, for the line B H divides the four-sided figure A B H O into two equal parts; hence, we conclude that the space described by a falling body in the 2nd second of its fall, is exactly *three times* the space passed through in the 1st second.

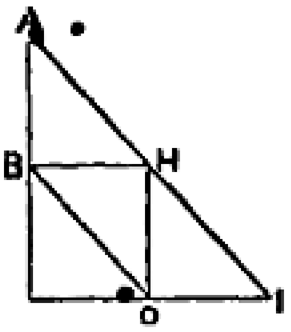


Fig. 8.

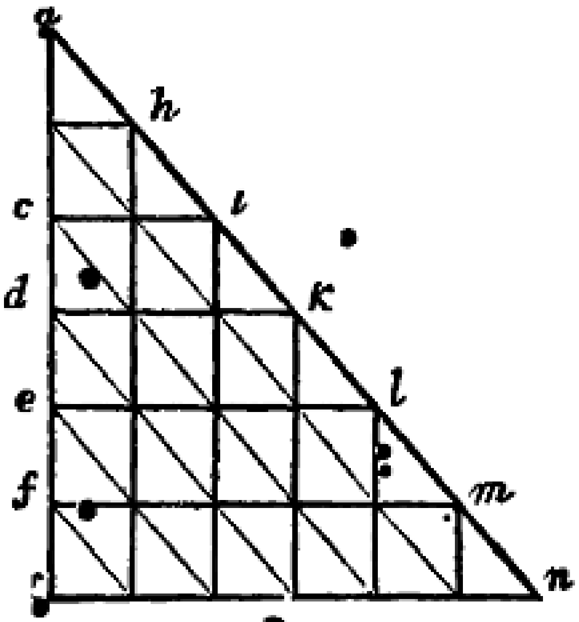


Fig. 9.

And if, by following out the process just described, we divide our whole triangle into a number of smaller ones, as in fig. 9, each equal to *a b h*, the mere inspection of such a triangle will show us that the space passed over in the 3rd second is *five times* the space passed over in the 1st; that the space passed over in the 4th second is *seven times* that passed over in the 1st; that the space of the 5th second is *nine times* that of the first; and the space of the 6th second *eleven times* that of the first. Hence, we arrive at the important conclusion that the spaces described in the succeeding seconds increase in the ratio of the odd numbers 1, 3, 5, 7, 9, 11, 13, &c. &c.

15. We shall now consider the spaces passed over, not in the seconds taken singly, but in any number of them taken together.

If the space passed over
in the first second be = 1
then the space passed over
in 2 seconds will be = $1+3=4$
„ 3 „ = $1+3+5=9$
„ 4 „ = $1+3+5+7=16$

and thus we might proceed for any number of seconds.

Ranging the times in one column and the spaces in another, we shall find that we have arrived at a remarkable and most important result.

$$\begin{array}{cc} \text{Times.} & \text{Spaces.} \\ 1 & \left.\begin{array}{c} 1 \\ 4 \\ 9 \\ 16 \\ \text{\&c.} \end{array}\right\} \\ \end{array}$$

$$\begin{array}{cc} 1 & 1 \\ 2 & 4 \\ 3 & 9 \\ 4 & 16 \\ \text{\&c.} & \text{\&c.} \end{array}\right\} \ldots \text{A.}$$

A glance at these figures will show us, that if we call the space passed over in the 1st second 1, the spaces are equal to the *squares of the times*. Thus, the square of 1 = 1, the square of 2 = 4, the square of 3 = 9, and so on.

16. But we must now be more precise. We have supposed the space passed over in the 1st second to be 1 merely for the sake of simplicity; the actual space passed over must, of course, be determined by experiment; and from the most exact experiments it has been ascertained that the space passed over by a body during the 1st second of its fall amounts to a little more than 16 feet; the fraction above 16 is small, and, to facilitate our calculations, we will neglect it.

17. We now come to real practice. Referring to fig. 9, it is evident that, no matter what the space passed over in the 1st second may be, the space passed over in the 2nd second will be *three times* as much, in the 3rd second *five times* as much, and so on. Hence, if we multiply the series of odd numbers at the bottom of the fourteenth paragraph by 16, we shall find the

spaces actually passed over by a falling body, during the successive seconds of its fall. These spaces are—

$$16 \times 1 = 16$$
$$16 \times 3 = 48$$
$$16 \times 5 = 80$$
$$16 \times 7 = 112$$
&c. &c.

It is also evident that, as we have increased the area of each little triangle from 1 to 16, the whole space passed over in any number of seconds will be 16 times what we have found it to be in the table marked A, p. 36. The spaces will be no longer *equal* to the squares of the times, but *proportional* to the squares of the times. The space passed over in 3 seconds, for example, will not be 9, but 16 times 9; the space passed over in 6 seconds will not be 36, but 16 times 36. Hence the following important practical rule, where it is desired to find, from the time of its fall, the space through which a body has fallen:—

18. *Multiply the square of the time in seconds by* 16, *the product is the space passed through in feet.*

By means of this simple rule we can solve a great number of interesting questions.

Example 1. A stone let fall from the top of the spire of Salisbury Cathedral is 5 seconds in reaching the bottom: required the height of the spire.

$$5^2 = 25$$
$$25 \times 16 = 400 \text{ feet.}$$

Example 2. An engineer requiring to know the depth of a coal-shaft, and having no string to measure it, let a stone fall into the shaft, and observed that it required 4 seconds to reach the bottom; required the depth of the shaft.

$$4^2 = 16$$
$$16 \times 16 = 256 \text{ feet.}$$

It may be remarked that the writer himself was once in the position here supposed, and found the knowledge of the rule which we are now discussing extremely useful to him.

19. If the problem be reversed, and the *space* be given to find the *time*, we must, of course, reverse our calcu-

lation. Supposing we have the height of Salisbury spire given = 400 feet, the time of a body's descent would be found as follows:—

$$\frac{400}{16} = 25$$
$$\sqrt{25} = 5 \text{ seconds}$$

or, expressed in words,—

20. *Divide the given space by* 16, *and extract the square root; the quotient will be the time in seconds.*

Example 3. A stone is cast from a boy's hand vertically upwards and returns again to his feet; the time occupied by the stone on its journey, up and down, is six seconds. To what height did it rise?

In this case the stone, as it ascends, moves with a uniformly *retarded* velocity, finally comes to rest, and then returns upon its path. It descends with a uniformly *accelerated* velocity, *the same time being occupied in the descent as the ascent.* Hence, the problem resolves itself into this one: given the time of a body's descent *three* seconds, required the space through which it has fallen:—

$$3^2 = 9$$
$$9 \times 16 = 144 \text{ feet},$$

which is the height to which the stone has ascended.

21. Relation of Time and Velocity.—In these examples we have confined ourselves to the relation between the space and time. We shall now endeavour to obtain a clear notion of the law by which the *velocity* is regulated.

Let the line $a\ g$, fig. 10, represent, as before, the time divided into seconds; the line $b\ h$ then represents the velocity at the end of the 1st second; the line $c\ i$ represents the velocity at the end of the 2nd second; but it is evident that the line $c\ i$ is double of the line $b\ h$, or, in other words, that the velocity at the end of the 2nd second is *double* of the velocity at the end of the 1st. In like manner, the velocity at the end of the 3rd second is *three times*, at the end of the 4th second *four times*, at the end of the 5th second *five times*, and at the end of the 6th, *six times* the velocity at the end of the 1st second; that is to say, the velocity increases in the same ratio as the time, or is proportional to the time.

22. If, then, we know the velocity at the end of the 1st second, the velocity at the end of any other second may be easily found. But here it is of the utmost importance that we should have a perfectly clear notion of what is now intended to be expressed by the word *velocity*. Supposing at the end of the 1st second, the action of gravity to cease suddenly, the body would move forward with the velocity which it had acquired at the end of the 1st second; but this velocity would be no longer accelerated; it would be *uniform*, for the continuous pull which causes the acceleration would be absent. Thus the velocity which a falling body possesses at the end of any time is the velocity with which it would proceed uniformly, *supposing the action of gravity to cease at that particular time.*

23. Now, as before observed, the space described by a body moving at a uniform velocity is represented by a rectangle, one of whose sides denotes the time, and the other the velocity. The little rectangle *b c h p*, fig. 10, therefore, represents the space passed over by a body moving with the uniform velocity *b h*, during the time *b c*. But *b c* represents one second, and *b h* is the velocity at the end of the 1st second; consequently the rectangle, *b c h p*, is the space through which the body would move in the 2nd second, if the action of gravity were to cease at the end of the 1st. But *b c h p* is equal to twice the triangle *a b h*, and since *a b h* represents the number 16, *b c h p* will represent the number 32; it is, therefore, proved, that supposing the force of gravity to cease at the end of the 1st second, the body would possess a velocity sufficient to carry it, in the next second, through a space of 32 feet; in

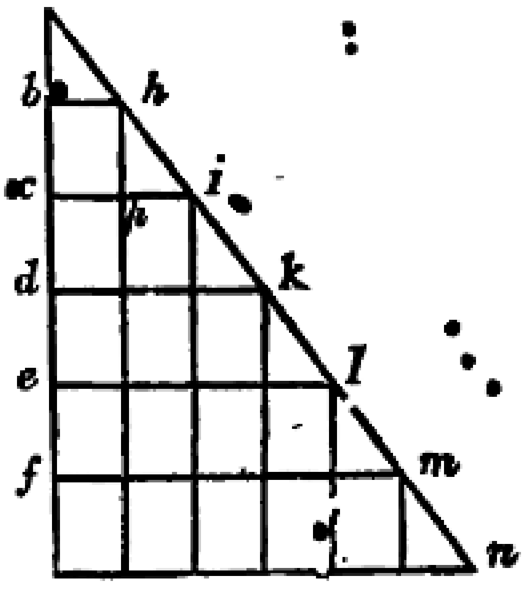


Fig. 10.

other words, it would possess a velocity of 32 feet a second.

I know that boys usually find a difficulty in distinguishing the space passed over in the 1st second from the velocity acquired at the end of the 1st second. It must be remembered that, in the 1st second, the body commences falling from a state of rest, and gradually increases in velocity; that, in fact, the first 16 feet are not described at any particular velocity at all. Now, when a velocity is said to amount to a certain distance per second, it is a *uniform* velocity which is always meant, and it would, therefore, be totally erroneous to say that the body moves through the 1st second of its fall with a velocity of 16 feet a second; these 16 feet are, on the contrary, the space described on the 1st second by the body moving with velocities gradually increasing from 0 to 32.

24. We must, then, regard the line *b h* as denoting the number 32; but here it may be demanded, how is it that the line *b h* must be regarded as 32, when a moment ago it was stated that the space *b c h p* is 32? Both statements, however, are perfectly consistent with each other; for, the side *b h* being 32, and the side $b\,c = 1$, as we suppose it to be, the area of the little rectangle will be $1 \times 32 = 32$.

In like manner the base *b h* being 32, and the height $a\,b = 1$, the area of the triangle *a b h* is 16, as it ought to be. We must not forget that the sides of a triangle or a rectangle are expressed in units of length, whereas the area is expressed in units of surface; and, in our case, the units of length express *time* and *velocity*, while the units of surface express *space*.

25. It being thus established that the velocity at the end of the 1st second is 32 feet, the velocity at the end of any given time may, as before shown, be found by multiplying the given time by 32: thus, the velocity at the end of 3 seconds is 96; at the end of 6 seconds it is 192; at the end of 10 seconds it is 320, and so on. If the velocity be given, we find the time necessary to produce it by dividing the velocity by 32. Thus, for example, a velocity of 320 feet a second

requires 10 seconds' action to produce it, a velocity of 384 feet a second requires 12 seconds, and so on.

Example 4. How many seconds must a body fall to acquire the velocity of a 24-lb. cannon-ball, which, according to the table at page 16, is 2400 feet a second?

$$\text{Here } \frac{2400}{32} = 75 \text{ seconds.}$$

Example 5. Through what *space* must a falling body pass, in order to acquire the velocity mentioned in the last question?

When the time is given, it has already been shown that the space is found by multiplying the square of the time by 16; hence, finding the time as in the last question, the rule referred to may be applied:—

$$75^2 = 5625.$$
$$5625 \times 16 = 90{,}000 \text{ feet.}$$

LESSON V.

MECHANICAL PROPERTIES OF LIQUIDS.

1. *What constitutes a Liquid.*—Matter is presented to us in three different forms, the solid, the liquid, and the gaseous or aeriform. No one of these forms is constant: by the application of heat the solid form may be converted into the liquid or gaseous, and by the application of cold, liquids, and even gases, can be converted into the solid condition. Although there is no difficulty in distinguishing liquids from solids or gases when we see them, still it is not very easy to define in a scientific manner what a liquid really is. In books on natural philosophy we usually find it stated that the molecules of a liquid body have no tendency, like those of a solid, to cohere, and that they are separated by the least force applied to them. But this can scarcely be accepted as a correct definition; for the following reasons:—

2. Every boy knows what a soap-bubble is, and that when the pipe from which it is blown is inverted, a drop, sometimes a large one, depends from the lower portion of the bubble. Now when we compare the weight of this drop with the thinness of the film which supports it, we must come to the conclusion that the strength of the film, or in other words, the force by which its particles cohere, is really very great. But it may be urged, that the film referred to is not one of water, but of soap mixed with water: there is, however, every reason to believe that the soap merely serves to diminish the *mobility* of the particles, without increasing their cohesion.

3. But we do not need soap to prove the strong cohesive force of liquids: if water be boiled for a long time so as to expel the air which it always holds in solution, the cohesion of the particles becomes so great that you can fill a long tube with the liquid, turn it upside down,

and the column of liquid will remain fixed in the tube, supported by its own cohesion. Water thus prepared, when enclosed in a vessel void of air, requires a far greater heat to make it boil, or in other words to tear its particles asunder so as to cause them to assume the form of steam, than ordinary water; and when it does boil, we do not find it commencing by a gentle ebullition, but suddenly, as if a spring were broken, the cohesion is overcome, and the heated water explodes like gunpowder.

4. We probably obtain a more correct notion of the nature of a liquid than that commonly entertained when we imagine its particles perfectly free to *slide* over each other in every direction, though the force which resists the tearing asunder of the particles may be very great. According to this view it is not the absence of cohesion, so much as the absence of *rigidity*, which distinguishes the liquid condition.

5. *Liquids transmit pressure equally in all directions.*—The most remarkable property of liquids is the power which they possess of transmitting pressure equally in all directions. Let A B C D, fig. 1, represent the section of a cubical vessel with tubular apertures in its sides. Into these tubes let the pistons *a*, *b*, *c*, *d*, fit water-tight, and let the vessel be filled with water until the surface of each piston shall be in contact with the liquid. If the piston *a* be now pressed downwards with any force, say the force of one pound, this pressure is not only transmitted to *c*, which is vertically under *a*, but also to *b* and *d*. If the pistons be all of the same size, it would require a force of a pound at *b*, *c* and *d*, to prevent these pistons from being forced out. Now, no matter where we may suppose our pistons to be placed, the same effect would

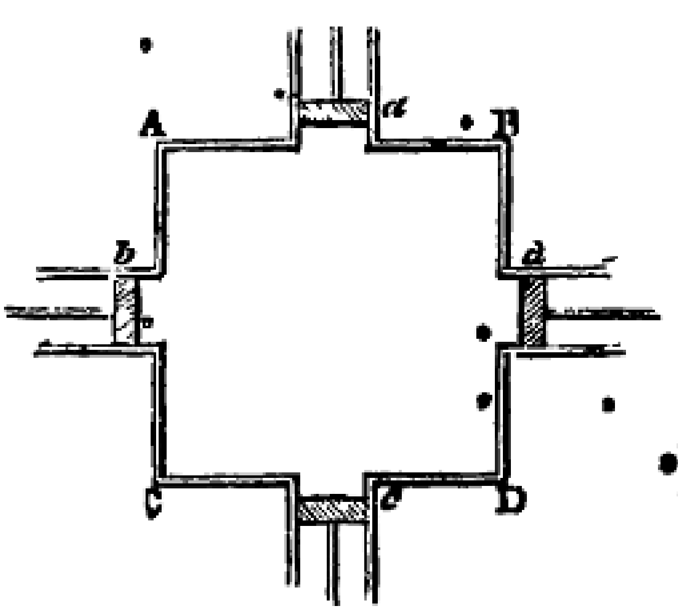


Fig. 1.

follow: so that if the piston *a* present an area of one square inch, a weight of one pound at *a* would produce a pressure of one pound on every square inch of the interior surface of the vessel.

6. If the pistons be not of the same size—if the area of *d*, for example, be two square inches instead of one—then a force of one pound acting on *a* would produce a pressure upon *d* equal to two pounds. In this case therefore a force of two pounds would be required at *d* to prevent the piston from being forced out.

This is a point of considerable mechanical interest, and it is therefore important to make it perfectly clear. Let A B C D, fig. 2, be a closed vessel having two cylinders C′ and D′ of unequal sizes passing through the top. Into these cylinders let the pistons *a* and *b* fit water-tight: suppose the area of *a* to be one square inch, and of *b* to be five hundred square inches: then if a force of one pound be applied at *a*, a pressure of one pound will be exerted on every square inch of the interior of the vessel, and hence a pressure of 500 lbs. will act upon the under surface of the piston *b*. To prevent the piston from being forced upward, a weight of 500 lbs. must be placed upon it. If, while things are in this state, an additional force of a pound be applied at *a*, the weight of 500 lbs. will be thereby lifted.

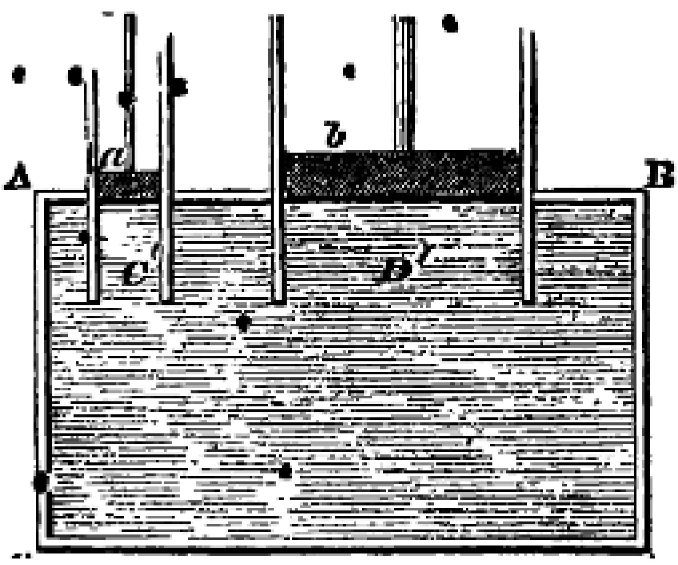


Fig. 2.

7. *The Hydrostatic Paradox.*—The fact of so small a force being able to raise so large a weight has given to the experiment which we have just described the name of the hydrostatic paradox; but let us examine wherein this paradox consists. When the piston *a* descends, it is true the piston *b* is raised; but ***how much*** is it raised? Suppose *a* to be pressed downwards

through the space of 1 inch; a column of water which fills this space will be forced into the cylinder *b*. But as *b* is 500 times the area of *a*, the little column will fill only the $\frac{1}{500}$th part of an inch of the cylinder *b*; that is to say, when the piston *a* is pushed down a full inch, the piston *b* rises only $\frac{1}{500}$th of an inch. Now the magnitude of the effect produced must be estimated by the height to which the weight is lifted, and we see that although the *weight* is very great the *height* is very small, the space passed through by the large piston being to that passed through by the small one in the inverse proportion of the area of the former to that of the latter. These considerations show that the experiment is in reality no paradox at all.

8. It is indeed no more a paradox than an experiment which boys make every day with a see-saw; for here it is well known that any boy, however small, may be made to balance any boy however large. I will ask you to imagine a see-saw, each of whose arms measured from the centre is 500 feet long. Let a boy one pound in weight be conceived to sit upon the extreme end of the plank, or in other words 500 feet from the centre; the chapter upon levers will show you that this boy will exactly balance another weighing 500 pounds, and sitting at a distance of *one foot* from the centre. Of course the weight and distances here supposed are quite absurd, but I choose them because they are the same as those used in the case of the "paradox." Here, then, we have a weight of 1 lb. exactly balancing a weight of 500 lbs.; and if while things are in this balanced condition a pound weight be placed in the hand of the small boy, he will sink and lift the other. But if we observe the space through which both boys pass, we shall find that the small boy must descend through 500 inches in order to lift the large boy 1 inch: it is evident that the case is very similar to that of the hydrostatic paradox.

9. *The Hydrostatic Bellows.*—If instead of placing a pound weight upon the piston *a*, fig. 2, we poured one pound weight of water upon it, the effect would of course be the same; and it is manifest that the result

would be in no way altered if the piston *a* were entirely removed, and the water simply poured into the tube which contains the piston; the liquid thus poured in would raise the piston *b*. This principle is applied in the construction of the hydrostatic bellows, a sketch of which is given in fig. 3. The bellows are made like those of an accordion or concertina. A and B are boards which are united by flexible leather: at T a tube is inserted which is bent upward to U. On the board A weights are placed, and into the tube U T water is poured: this water enters the bellows and raises the weights.

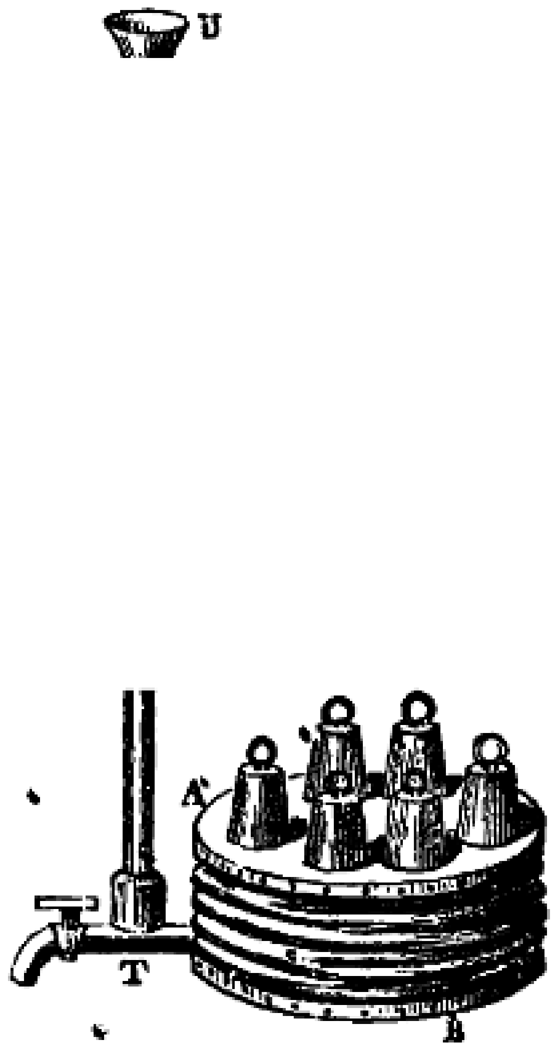


Fig. 3.

10. Let us now suppose the two cylinders C′ and D′, fig. 2, to be prolonged to the bottom of the vessel so as to form two separate cylinders, as shown in fig. 4, and let these two cylinders be united by the open passage *p*. It is evident that all that has been said regarding fig. 2 applies also to fig 4. When *a* is pressed down, the water will be forced through *p* into the other cylinder; so that a pressure of a pound at *a* will, as before, produce a pressure of 500 lbs. on *b*.

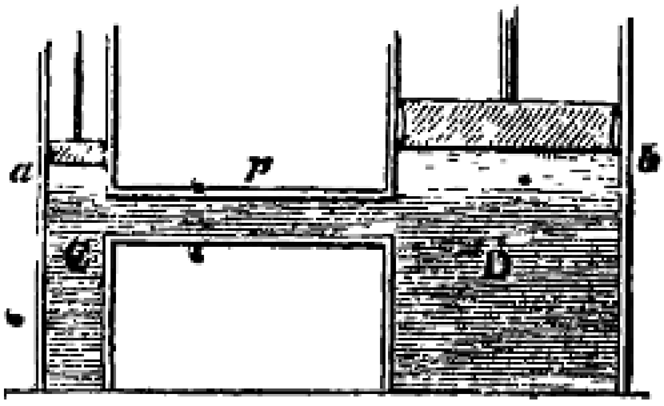


Fig. 4.

11. Another step carries us to the construction of the well-known hydraulic press, or Bramah's press, as it is sometimes called, which I hope you will now find

little difficulty in understanding. A simple form of the machine is sketched in fig. 5. C and D represent

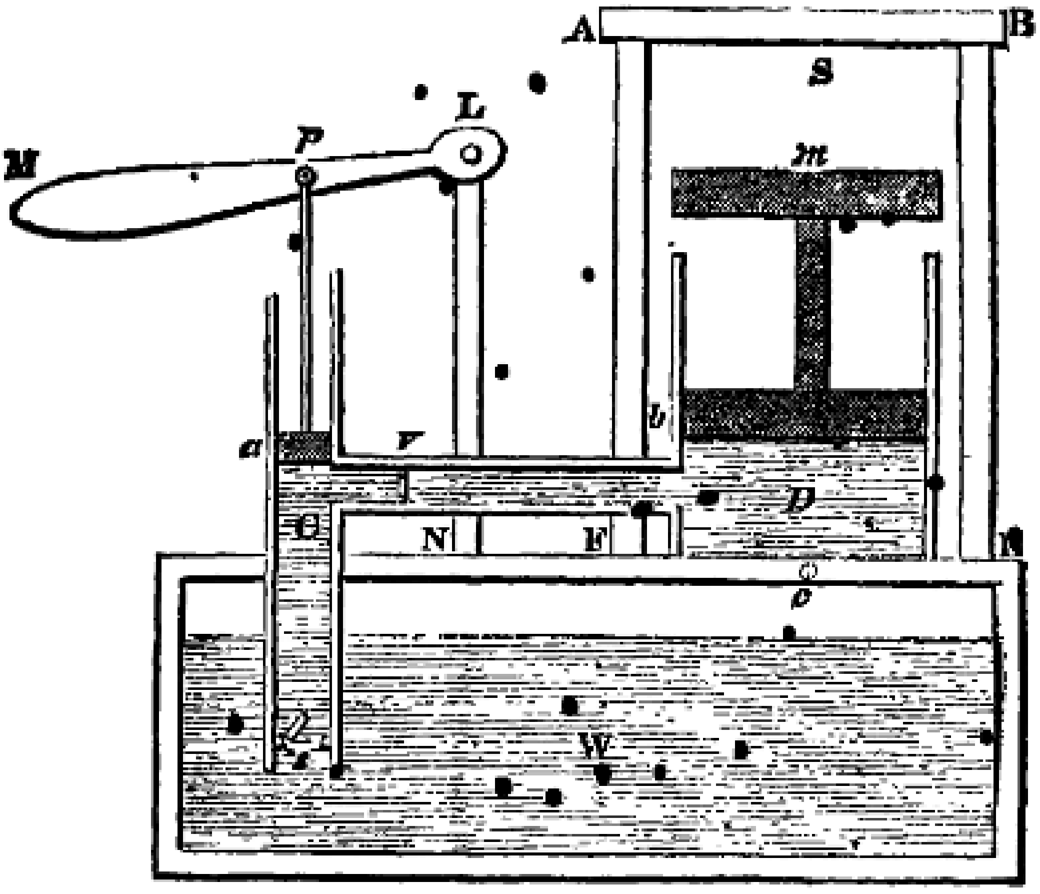


Fig. 5.

two cylinders as before; C however now dips into a cistern of water W, while D terminates at the top of the cistern. N L is a strong upright to which the lever L M is attached by a pivot at L: a pin *p* connects this lever with the piston *a* of the small cylinder, and it is evident that by raising or lowering the end M the piston may be caused to ascend or descend. At *v* in the cross passage is a valve which opens towards D, and at *s* at the end of the small cylinder is another valve which opens upwards. Attached to the piston-rod of *b* is a strong metal plate *m* which, of course, rises and sinks with the piston underneath. A B E F is a strong framework, the top A B of which represents the section of a second strong metallic plate.

12. We will now describe the action and use of this instrument. When the piston *a* is raised, it is plain that the water will follow it through the valve *s* as in the case of a common pump. When the piston ceases to ascend, the valve *s* falls by its own weight, and thus prevents the water from returning to the cistern W. When therefore the piston *a* is pushed downwards, the

water is forced through the valve *v* into the cylinder D, and is prevented from returning by the closing of *v*. On raising the piston again, the valve *s* opens and the cylinder C is filled with water, which by the descent of *a* is forced into the cylinder D as before. It is evident, that by a succession of plunges we gradually raise the piston *b* and the plate above it, and that if any body be placed in the space S, it may be forcibly squeezed between the plates A B and *m*. If, as already supposed, the piston *b* be 500 times the area of the piston *a*, then a pressure of 5 lbs. exerted on *a* will produce a pressure of 2,500 lbs. on *b*; and hence is capable of pressing the body placed above *m* with a force of 2,500 lbs. I have intentionally made the figure as simple as possible, it being my object to make the principle perfectly clear; in practice the machine is variously constructed, but if the pupil understands the above description thoroughly, a little reflection will enable him to master the most complicated machines of this description. At *c* there is a cock through which, when it is required to empty the cylinder D, the water flows back into the cistern.

LESSON VI.

PRESSURE AND DISPLACEMENT.

1. ***Pressure of a liquid on the sides and bottom of its containing vessel.***—If a cubical vessel contain a solid mass which fills it exactly, the sides of such a vessel may be removed, while the mass within it retains its position, and presses with all its weight upon the bottom of the vessel. The sides do not at all contribute to sustain the mass, and whether they are present or absent, is a matter of indifference. If, however, the same vessel be filled with a liquid, the sides are necessary to preserve the shape of the mass; the liquid exerts a pressure upon the sides, and if the latter were removed would inevitably flow away in all directions. It is evident, however, that the sides, being vertical, do not contribute to the support of the weight of the liquid, but that, just as in the case of the solid body, the bottom of the vessel bears all the weight. The pressure, then, upon the bottom of any vessel with upright sides is equal to the weight of the liquid within the vessel.

2. Now it is a singular consequence of the property possessed by liquids, of transmitting pressure in all directions, that the pressure upon the bottom of a vessel of any shape whatever is equal to that exerted on the bottom of a vessel with upright sides, provided only that the bottom of the latter is of the same area as that of the former, and that both vessels are filled to the same height with liquid. This is proved by means of the apparatus sketched in fig. 6. A B C is a bent tube, furnished at A with a collar, on which vessels of different shapes may be screwed water-tight. Supposing the tube to be filled with mercury up to A, the mercury will stand at the same level C in the opposite arm of the tube. The point C being carefully marked, let the cylindrical vessel *g* be screwed on to A. If water be now poured into *g*, say to the height *h*, it will cause the column in the other branch of the tube to rise to *k*, the ascent being evidently due to the pressure of the water upon the surface of the mercury underneath. The point *k* being carefully noted, let *g* be now removed, and let the vessel *m* or *n* be screwed on to A; let water be poured into it until the height of the surface of the water above that of the mercury at A is the same as it was in the last experiment. On observing the other branch of the tube, it will be found that the height through which the column has been elevated is exactly the same as before; *k* will mark the summit of the column.

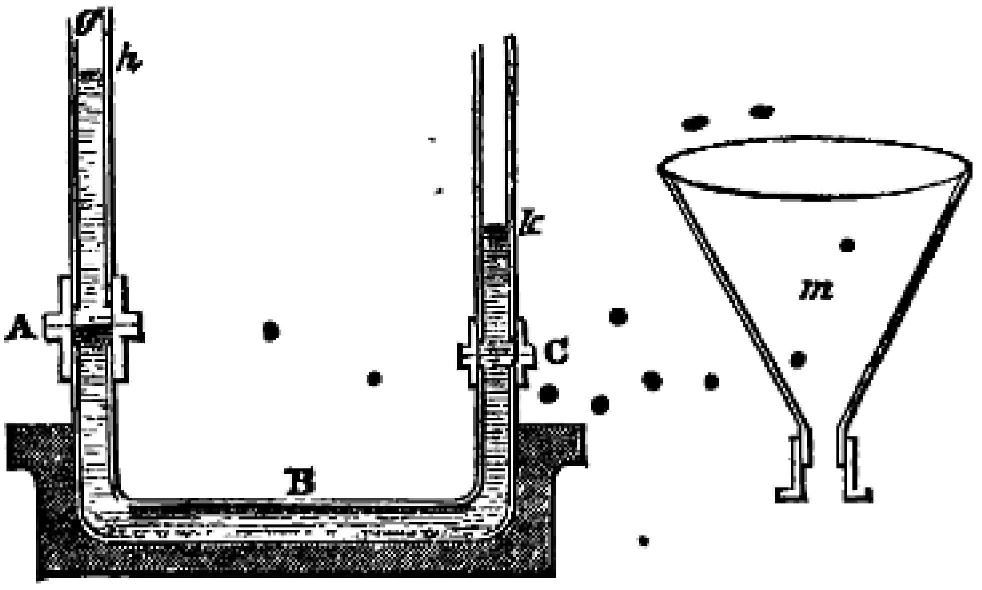


Fig. 6.

3. Hence we see that the pressure upon the bottom

is influenced only by the *height* of the liquid column and the area of its base. The pressure on the bottom of any vessel, no matter what may be its form, is always equal to the weight of a cylinder of the liquid, with a base equal to the bottom of the vessel, and a height equal to the height of the water within it. The pressure is wholly independent of the *quantity of water* as long as the bottom is of the same size, for we have seen that the bottom of the vessel *m*, fig. 6, sustains precisely the same pressure as that of *n*, although the quantities of water which the vessels contain are very different. It is thus evident that by suitably choosing the shape of a vessel we may produce an enormous pressure with a single pint of water. Supposing, for example, that we choose a vessel with a square bottom, which measures 4 inches every side, the area of this bottom is 16 square inches; and if the vessel be so narrowed upwards that when the pint of water is poured into it the surface shall be two feet above the bottom, the pressure borne upon the bottom in this case will be fully fifteen pounds, for this is the weight of a cylinder of water whose base is 16 inches and height 2 feet.

4. We here see very clearly the explanation of an experiment cited in some old treatises on natural philosophy, and which at first sight seems very startling. A strong cask *a* was filled with water, and through the cask was introduced a long tube *c d*; on pouring water into the narrow tube, the cask being unable to resist the pressure thus produced, burst asunder. Supposing such a tube to be 18 feet long, and to possess a section of 1 square inch; when filled to the top with water, the pressure of the liquid cylinder at the point *c* would be equal to its weight, which is about 8 pounds. This pressure would be transmitted to every square inch of the interior sur-

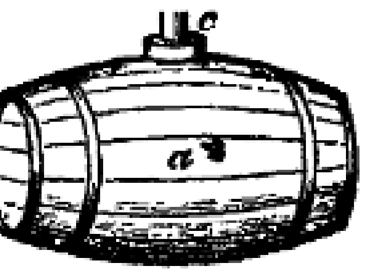


Fig. 7.

face of the cask, and supposing the number of square inches to be 7000, which is quite within ordinary bounds, to preserve itself from bursting, the cask must be able to bear a pressure of 56,000 lbs.; this enormous effect being produced by the judicious disposal of a very small quantity of water.

5. The pressure of a liquid is not, however, confined to the sides and bottom of the vessel which contains it, but every portion of the liquid mass itself sustains a pressure which depends upon its depth below the surface. A flat fish, for example, swimming at a depth of 32 feet below the surface of the sea, sustains the downward pressure of a column of water whose base covers the fish, and whose height is 32 feet. If the back of the little fish be 12 square inches in area, it will, at this depth, exist under a downward pressure of 180 pounds, and it may be asked, why does not the animal sink under this pressure? The reason is, that the fish is pressed as much upwards by the water as downwards, and these two opposite pressures balance each other, so that the fish moves as if it suffered no pressure at all. The fish being thus squeezed, it may however be asked, why it is not crushed to pieces? the reason is, that the tissues and liquids which constitute the body of the fish exert a pressure against the surrounding water equal to that which it exerts against them. The materials of which the fish is composed are, like the water itself, almost perfectly incompressible. Some fish, indeed, are furnished with air-bladders, and when such fish swim at great depths, the bladders are very much compressed; the consequence is, that when suddenly removed from those depths by the hook of the fisherman, the air-bladder swells like a balloon, and thus causes the appearance which we observe at the fish-stalls, where the stomach of a fish is often seen forced through its mouth by the distension of the air within its body.

6. *Compressibility of Water.*—In connexion with this portion of our subject it may be asked whether water itself is not much compressed at very great depths. So small is the compressibility of water,

that it was for a long time believed to be absolutely incompressible. An experiment was once made in Florence which is very celebrated in the annals of science. A hollow sphere of gold was filled with water and carefully closed. Now it is a geometrical fact that a sphere takes up more space than any other body which possseses a surface of the same area; hence if a hollow sphere be caused to change its shape, without either stretching or shrinking, the new shape will occupy less space than the old one. The aim of the Florentine experimenters was to squeeze their sphere of gold so as to make it change its shape, for they knew if this were effected, that the water within the sphere would be compressed into a smaller space. They found, however, that they could not change the shape of the sphere, although the pressure applied was so great as to cause the liquid to ooze through the pores of the gold, and to collect like dew upon its surface. A similar effect was observed very recently in Manchester, during some experiments made to determine the influence of pressure upon the melting points of solids. Melted spermaceti contained in a brass cylinder was subjected to a pressure so great that the liquid was forced in invisible jets through the pores of the brass until the cylinder was quite emptied of its contents.

7. It is now known, however, that liquids are compressible in a small degree, and various instruments have been constructed to demonstrate the fact. Perhaps the simplest proof is the following:—A vessel *d*, fig. 8, carefully filled with water, has a solid plunger *p* entering through its neck; on the plunger, and immediately in contact with the mouth of the vessel, a ring is fitted so as to be capable of being pushed along the plunger, still clasping the latter so tightly as to remain in any position in which it is placed. Such a vessel was sunk to a great depth in the sea, and on being raised again, it was found that the ring had been moved, and stood at some distance above the mouth of the vessel. This proved that the plunger

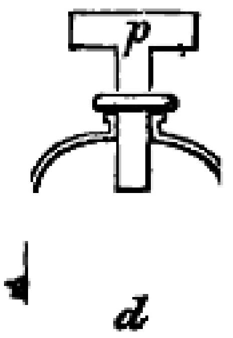


Fig. 8.

had been forced into the vessel below, or, in other words, that the water within the vessel had been squeezed into a smaller compass: when the vessel was drawn up, the liquid within it, being relieved from the pressure, resumed its former dimensions, and forced out the plunger which carried the ring along with it.

8. *Principle of Archimedes.*—We now proceed to consider a point which has a great traditional interest connected with it. It is reported that Hiero, king of Syracuse, having given a quantity of gold to a goldsmith to make him a crown, suspected that the man had substituted for a portion of the gold a baser metal, and that the crown returned to him, although of the proper weight, was not of the proper material. He asked Archimedes, one of the most celebrated characters of antiquity, to determine whether his suspicions were correct. It must be remembered that in those days people knew nothing of the tests which would now render the solution of the problem a very simple matter, and that it was therefore a question of exceeding difficulty: but a problem must be very difficult indeed which resists the continued application of the human mind; for such application is almost always rewarded by the streaming in of light, even from unsuspected quarters. Archimedes found this to be the case. While pondering upon the subject, he chanced to enter a bath which had been filled brim full of water, and observed, as he entered, that the liquid flowed over the edge. Prepared by the mental discipline which he had previously gone through, the solution of the problem at once flashed upon him, and it is related that he sprang in ecstasy from the bath, and ran through the streets of the city, crying, "Eureka! Eureka!" "I have found it! I have found it!" We will now consider how the simple circumstance to which we have referred could have proved so instructive as to make the great ancient philosopher almost mad with joy.

9. By comparing a shilling with a sovereign, any boy can satisfy himself that gold is much heavier than silver—indeed, it is nearly twice as heavy. A pound of silver is therefore larger than a pound of gold, and if

immersed in a vessel accurately filled with water, the former will cause nearly twice as much water to flow over as the latter. If a mixture of gold and silver of the same weight were immersed, the quantity of water displaced would be something less than that displaced by pure silver, and something greater than that displaced by pure gold; and here was the secret of the test of Archimedes. He took the king's crown, and procured a quantity of pure gold of the same weight; he immersed the crown and the gold successively in water, and found that the crown displaced more of the liquid than the gold did. The problem of the king was thus solved, and the dishonesty of the astonished goldsmith completely demonstrated.

10. But we have not yet derived all the instruction possible from this important discovery, and this we must endeavour to do. When a bather walks in water which reaches to his chin, he finds that the soles of his feet press very lightly upon the bottom; a portion of his weight is borne by the water; if it were deep enough to reach a little above his eyes, his whole weight would be borne by the liquid, and the bottom would not be at all necessary for his support. Hence it is that a person finds it easy to lift a mass of stone under water, which, when he brings it to the surface, altogether surpasses his strength, and that a body weighed in water appears to lose a considerable portion of its weight. The question now is—how much of its weight does the body lose? How much of its weight is the water able to support?

11. When a lead bullet is immersed in water, it displaces a sphere of water exactly equal to the bullet in size: imagine such a sphere of water in the midst of a mass of the liquid: it is evident that the sphere is borne by the water, and neither sinks nor rises. Hence when the lead bullet occupies the place of the sphere, a portion of its weight, equal to the weight of a sphere of liquid of the size of the bullet, must be borne by the water. This leads us to the statement of the most important principle of hydrostatics, called the principle of Archimedes, namely, *that a body immersed in a liquid*

loses a portion of its weight equal to the weight of the quantity of liquid which it displaces.

12. If what I have here stated should be found difficult to understand, the difficulty will disappear when we go through the experimental proof of the principle. Let a *hollow* cylinder, *c*, be attached to one arm of a balance, fig. 9, and to this let another *solid* cylinder, *p*, be attached, of such a size as accurately to fill the hollow cylinder placed above it. By placing weights in the opposite scalepan, the balance-beam may be brought into a horizontal position; and when this is accomplished, let the cylinder *p* be caused to dip into a vessel of water. The equilibrium is now destroyed; *p* loses a portion of its weight, and consequently the end of the balance to which it is attached is raised by the weights in the opposite scalepan. The question now is, how much of its weight has *p* lost? or, more correctly, how much of its weight is borne by the water? Let water be poured into the hollow cylinder *c*, and it will be found that when the cylinder is full of water the balance-beam stands once more exactly horizontal. The weight, therefore, lost by *p* is exactly made good by the weight of a mass of water equal in size to *p*, and this is the experimental proof of the principle of Archimedes.

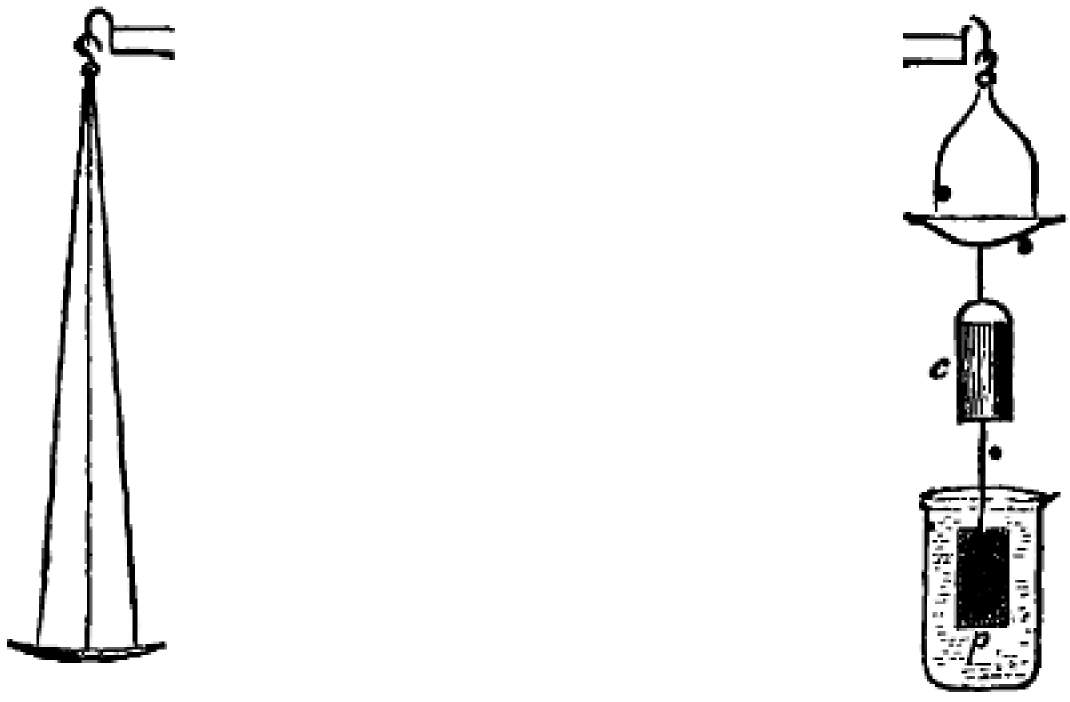


Fig. 9.

LESSON VII.

SPECIFIC GRAVITY.

1. **We** shall now see the utility of the principle which we have just established. It is of course of the highest practical importance to be able to compare the weights of different substances with each other. This might be accomplished by reducing the substances to the *same size*, and then weighing them in the ordinary manner; in this way it would be found that if the weight of a cube of silver be 10 grains, or 10 ounces, or 10 lbs., the weight of a cube of gold, of the same size, would be very nearly 19 grains, 19 ounces, or 19 lbs. It would, however, be a work of great difficulty, and indeed, in many cases impossible, to reduce bodies to the same dimensions, and here the principle of Archimedes comes to our assistance. Supposing a body which weighs 6 ounces to lose 2 ounces of its weight in water, the principle referred to teaches us that these 2 ounces are the weight of a mass of water of the same size as the body immersed, and hence the weight of this body would be *three times* that of water. In like manner, supposing the weight of a body of 27 ounces to be reduced to 24 ounces in water, we know that the difference, 3 ounces, would be the weight of a bulk of water equal to that of the body; and hence the latter must be regarded as 9 times heavier than the former. Calling the weight of water 1, the weights of the two bodies last alluded to would be represented by the numbers 3 and 9; and these numbers, 1, 3, and 9, are called the *specific gravities* of the substances to which they correspond. In the determination of specific gravities, the weight of distilled water, at a certain temperature, is usually taken as a standard, and represented by the number 1; and when in printed tables we find the specific gravity of gold stated to be 19·26, and that of silver 10·47, it is understood that the specific gravity of water is unity. Reflecting on what has been said, the reason of the following practical rule will be evident:—*Divide the real weight of the body by the*

weight it loses in water; the quotient will be the specific gravity.

2. In order to illustrate the foregoing, and to prepare us for what is yet to come, we will here propose a few exercises.

EXAMPLE 1. A body, weighing 52 lbs., loses 13 lbs. of its weight in water; another body, weighing 16 lbs., loses 2 lbs. of its weight in water; what ratio does the weight of a cubic inch of the former substance bear to the weight of a cubic inch of the latter?

A cubic inch of the former body is readily found, by the method we have just described, to be equal in weight to 4 cubic inches of water, while a cubic inch of the latter body is found, by the same process, to be equal in weight to 8 cubic inches of water; it is, therefore, plain that a cubic inch of the first body weighs only half as much as a cubic inch of the second.

EXAMPLE 2. A body, weighing 25 lbs., loses, when immersed in water, 5 lbs. of its weight. It is then joined to a second body weighing 12 lbs.; and it is found that the compound body, formed by the union of both, loses 9 lbs of its weight in water: required the specific gravity of the second body?

Here we find the weight of a mass of water equal in bulk to the first body to be 5 lbs.; and the weight of a mass of water equal in bulk to both bodies together equal to 9 lbs. Deducting 5 from 9, we find the weight of a mass of water, equal in bulk to the second body, to be 4 lbs.; but the weight of the body itself is 12 lbs., and consequently, dividing 12 by 4, we obtain its specific gravity = 3.

EXAMPLE 3. Let everything remain as in the last question, except that the compound body loses 20 lbs., instead of 9 lbs., by immersion; required the specific gravity of the second body?

Here, as before, the weight of a mass of water, equal in bulk to the first body, is 5 lbs., and the weight of a mass, equal in bulk to the compound body, is 20 lbs.; deducting 5 from 20, we find 15 lbs. to be the weight of a mass of water equal in bulk to the second body. But the weight of the body itself is 12 lbs., and consequently its specific gravity, found by dividing 12 by 15, is $=0\cdot8$.

3. In our first illustrations we intentionally restricted ourselves to those bodies which are *heavier* than water, and which therefore *sink* in the liquid; but the last example reveals to us the method employed when the specific gravity of a body *lighter than water* is sought. The body is attached to a second one of such a density that both together sink in water, and the precise steps indicated by the question are pursued.

4. In the determination of the specific gravity of liquids, the difficulty of reducing the bodies to the same dimensions disappears. The method pursued by chemists, who aim at very accurate determinations, is to provide a small glass flask with a ground-glass stopper, and ascertain the precise weight of the quantity of liquid which the flask is able to contain. Filling the flask, first with water, and afterwards with the liquid whose specific gravity is to be determined, we can compare the weights together, and thus obtain the specific gravity sought. There is another way, however, of determining the specific gravities of liquids, which depends upon the principle that the denser a liquid is, the *less deeply* will a floating body sink in it. Salt water being heavier than fresh, a floating body will not sink so far in the former as in the latter, a fact well known to those who are accustomed to swimming in rivers and in the sea. In sulphuric acid a floating body will sink to little more than half the depth that it sinks to in water; and many bodies which sink *wholly* in the latter continue floating in the former. Mercury is a still more striking example of the influence of density, for iron will float upon it just as wood floats upon water.

5. The *whole weight* of a floating body is borne by the liquid in which it floats, and the weight of the liquid it displaces is exactly equal to the weight of the body. A piece of wood, weighing 5 ounces, displaces 5 ounces of the liquid which supports it; it will displace 5 ounces of water, or 5 ounces of alcohol; but as water is heavier than alcohol, the latter 5 ounces will be larger than the former, and consequently the body

must sink deeper in alcohol than in water. It is easy to see that the specific gravities of two liquids are inversely proportional to the quantities of them displaced by the same floating body; if the quantity displaced, or, in other words, if the bulk of the immersed portion of the floating body in one liquid be twice what it is in the other, the specific gravity of the former is evidently one-half that of the latter.

6. To ascertain with precision the quantity of liquid displaced by the floating body, a shape is given to it similar to that sketched in fig. 10. G is a hollow globe, to which, on the one side, a tube, *c*, of uniform thickness, is attached, and which is united on the other with a vessel, *v*, in which a quantity of mercury is enclosed. The use of the mercury is to cause the instrument to stand upright in a liquid, and its quantity is so regulated that when the instrument is immersed in the heaviest liquid which it is destined to test, the hollow ball shall be barely covered by the liquid, while when it is immersed in the lightest liquid which it is intended to test, the stem *c* also shall be nearly submerged. Supposing the volume or bulk of the instrument up to the point where the stem is cut by the surface of the heavier liquid to be expressed by the number 1000, and the volume up to the point where the stem is cut by the surface of the lighter liquid to be 1100, it is evident that the specific gravities of the two liquids are to each other in the inverse ratio of these numbers, and supposing the lighter liquid to be water, the specific gravity of the heavier one would be 1·1. If we divide the interval between the two points alluded to into a number of equal parts, it is plain that by observing the point at which the surface of any liquid cuts the stem, we can ascertain the specific gravity of the liquid. In practice the stem is so graduated that the specific gravity can be at once read off.

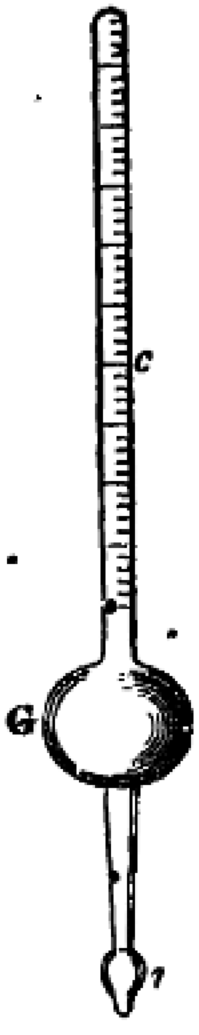


Fig. 10.

There are various mechanical contrivances for the determination of the specific gravities of solid and liquid bodies; but if the pupil understand the principles which we have endeavoured to expound, he will find little difficulty in comprehending such contrivances, or indeed in adding to them new inventions of his own.

LESSON VIII.

MECHANICAL PROPERTIES OF AIR.

1. Both liquids and gases are comprised under the more general term *fluids*. The Germans have no single word answering to our word liquids, and they distinguish liquids from gases, by calling the former "droppy fluids"—fluids capable of being poured out into drops like water, and *elastic fluids*, of which air is a type. If you compress air, you will find that it resists, and on removing the pressure, it expands again to its former size. Air is elastic because of the mutual repulsion of its particles; if the volume of a vessel containing a given quantity of air be doubled, this repulsion will cause the air to expand and fill the vessel. Here a reflecting boy may ask why it is that the atmosphere is not dissipated by this elastic force, since the atmosphere is enclosed in no vessel, and has free space to diffuse in. The reason is, that the earth is within the atmosphere, and holds the latter swathed round it by the force of gravity, which acts in opposition to the force by which the particles of air mutually repel each other.

2. The atmosphere is in fact an ocean of gas, which encompasses the earth. We have seen in the case of liquids, that at great depths, the water of the sea is compressed into a smaller space: this holds true in a far more striking degree in the case of air. The air near the surface of the earth, or in other words near the bottom of the air-ocean, is far more dense than at some elevations which even man has attained. Had De Luc, or Gay Lussac, or Mr. Walsh, in his recent balloon ascent, taken with him a bladder half filled with air from the earth's surface, he would have found that before his highest elevation was attained, the air would have filled the bladder. Being relieved from the weight of a

stratum of dense air, eighteen or twenty thousand feet in thickness, the elastic force of the air within the bladder would cause it to expand, until at length the air would press against the sides of the bladder and distend it.

3. But does the air possess weight? Most certainly; as may be proved in the following manner:—Let a flask A, fig. 11, exhausted of air, be suspended from one end of a delicate balance; and let weights exactly sufficient to sustain the flask be placed upon the opposite scalepan. If the cock *c* be now opened, the air will enter the flask A, and the moment it does so, the flask will sink, thus demonstrating the weight of the air which has entered it.

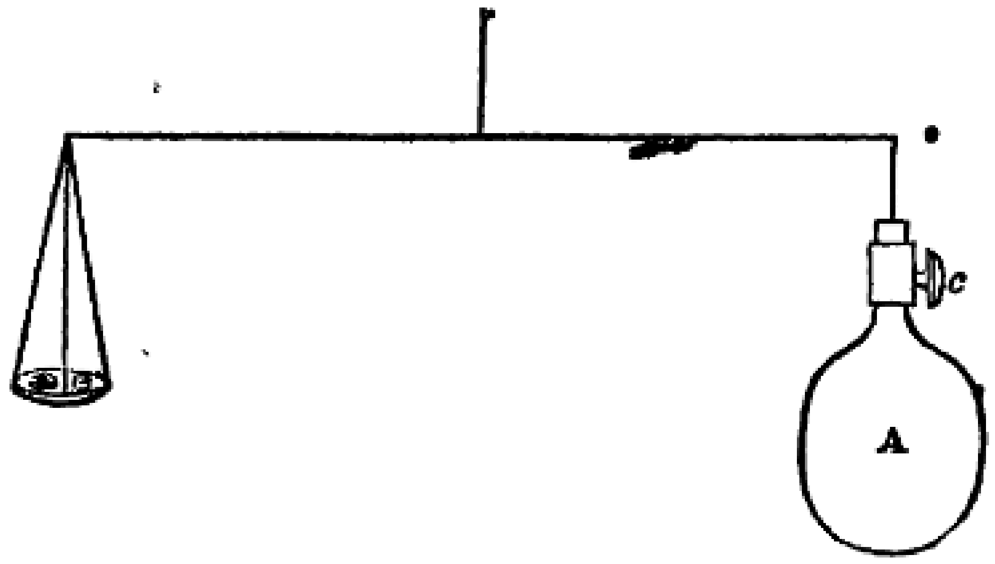


Fig. 11.

4. *Pressure of the Atmosphere.*—The air being thus proved to possess weight, the atmosphere under which we live must exercise a certain pressure on the earth's surface, and on all things upon that surface. This is the case. Conceive a column of air with a base of one square inch, extending from the surface of the sea to the top of the atmosphere; such a column would weigh about 15 lbs., and consequently would exert a pressure of 15 lbs. on the square inch of surface which supports it. For this reason an amount of pressure equal to 15 lbs. per square inch is called *an atmosphere;* 30 lbs. per square inch, two atmospheres; 45 lbs. per square inch, three atmospheres, and so on. As in the case of liquids, the pressure is equal in all directions: every square inch of the human body bears a pressure

of 15 lbs., and hence the total pressure upon a full-grown man must amount to several tons. Why then are we not crushed? our answer must be the same as that already given in allusion to fish at great sea depths. The solids, liquids and gases of the human body exert an outward pressure which exactly balances the inward pressure of the atmosphere.

5. *Discovery of the Weight of the Atmosphere.*—The discovery that the atmosphere possesses weight is a very celebrated one. Before the time of Galileo, a man eminent in science, and who was chiefly instrumental in overturning the system of false philosophy which was prevalent in his day, it was never thought that the air possessed weight. Pumps had been used; but nobody seemed to entertain the idea that there was any limit to the height to which water could be raised by a pump. I will here give a very brief description of this machine. A B, fig. 12, is a tube, one end of which, B, dips into water: into the tube a piston *p* is fitted air-tight, and can be pushed downwards or raised upwards by means of a handle attached to the rigid rod *c d.* Through the piston a passage is bored; and this passage is closed at times by a little door or *valve*, which can only open upwards. Conceive first the space immediately below the piston, to be filled with air: when the piston is pushed downwards, the air below it will lift the valve and escape: when the downward motion ceases, the valve falls by its own weight. If now the piston be drawn up, the valve being closed, no air can reach the space below it; the space, if it remained empty, we should call a ***vacuum.*** But it does not remain empty; for, as the piston

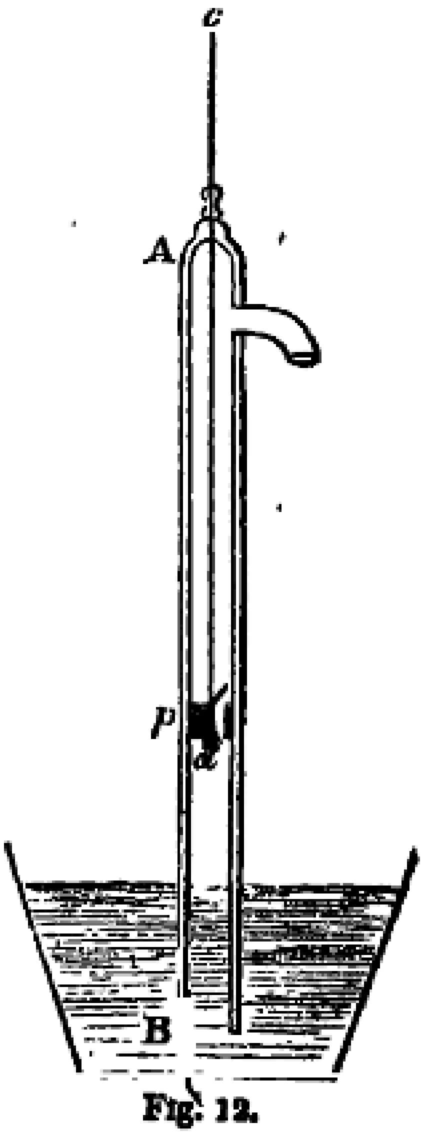


Fig. 12.

ascends, it is followed by the water; and when the piston descends again, water instead of air rushes through the valve and gets above the piston. On raising the piston again, this water is lifted, for it cannot return through the valve, and finally escapes through the spout of the pump.

6. In this experiment the piston appears to *suck* the water after it, and hence the name of sucker which is sometimes applied to this portion of the machine. Before the time of Galileo, it was never thought that there was a limit to the height to which water could thus follow the so-called sucker. Some gardeners in Florence chanced to sink a very deep pump, but found to their great astonishment that they could not get the water to rise to a greater height than 32 feet. The explanation given by the philosophers of those days of the ascent of water in a pump was, that *nature abhorred a vacuum*, and that hence the water rushed in to fill the empty space created by the ascent of the piston. By this pompous language they deceived themselves, and hid their ignorance under a figure of speech; nevertheless, the explanation was sufficient to satisfy the world for two thousand years. The gardeners in their difficulty came to Galileo, and he, old man, embittered by the persecutions he had suffered for declaring the truth and opposing error, replied sarcastically to his questioners: "It is evident that nature abhors a vacuum only to the extent of 32 feet." He did not however solve the problem: this was reserved for his pupil Torricelli to accomplish.

7. Torricelli reasoned thus:—These 32 feet of water must be *lifted* by something. Their weight is the measure of the force which lifts them: what can this force be? Perhaps the atmosphere has weight, and that it presses upon the surface of the water without the pump: if this be the case, and the air within the pump be removed by the piston, the outward pressure of the atmosphere being no longer balanced, the water will rise in the pump. But when the liquid column has attained such a height that its weight balances the weight of the atmosphere, beyond this the column cannot

rise. From the experiment made by the gardeners, it is therefore to be inferred that a column of water 32 feet high exactly balances the weight of the atmosphere.

8. *Experiment of Torricelli.*—But if this be the case, when we take a liquid *heavier than water*, the height to which it can be lifted ought to be *less*, than the height to which water is raised. Mercury, for example, is about 13 times heavier than water, granting then that a column of water 32 feet high is sustained by the atmospheric pressure, the column of mercury sustained ought to be only the thirteenth part of 32 feet, or in round numbers, 30 inches in height. Here then the experiment was suggested, which has made the name of its author famous. Torricelli took a tube *t*, fig. 13, more than 30 inches in length, open at one end, but closed at the other. Filling it with mercury, he stopped its open end by his thumb, and inverted it in a vessel *v* containing a quantity of the liquid metal. Judge of his satisfaction when he saw the liquid descend until the surface of the column within the tube was 30 inches above the surface without, and remain stationary in this position; thus fulfilling, in the most complete manner, the conclusion at which he had arrived.

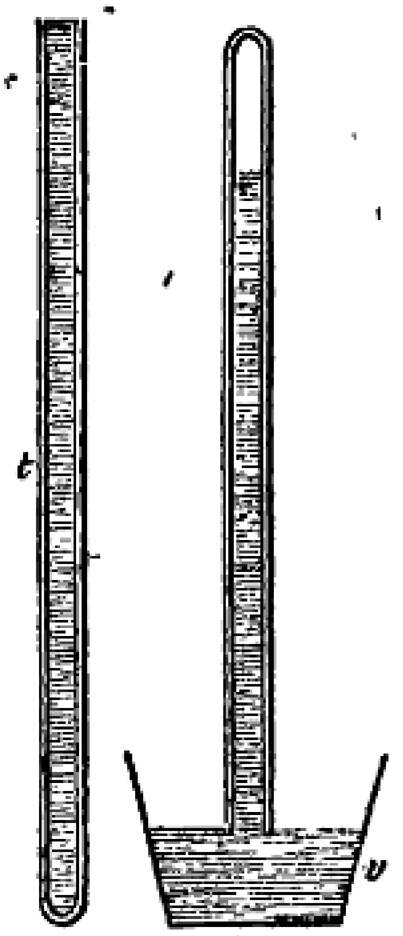


Fig. 13.

9. I would here direct your attention to the manner in which thoughtful reflection and experiment go hand in hand with a true natural philosopher, as Torricelli proved himself to be. If the former be not the prompter and guide of the latter, we wander blindly amid our experiments, and amass facts to little purpose. The opponents of Torricelli—for we must remember that he and his great master had nearly the whole world opposed to them—furnish us with an instructive example of the influence of prejudice upon the human mind. Sooner than accept the simple explanation of Torricelli, that the

column of mercury was supported by the atmosphere, a distinguished Abbé in those days affirmed that it was suspended by invisible threads! Natural Philosophy does not demand of its followers any unsteadiness of character, or unstable shifting from one opinion to another; but it requires that the love of truth shall be so predominant, that whenever truth appears, no personal feelings of our own shall be strong enough to prevent us from accepting it.

LESSON IX.

CHANGE OF ATMOSPHERIC PRESSURE—THE BAROMETER.

1. *Decrease of Atmospheric Pressure with the Height.* —Following the Torricellian experiment to its consequences, we should infer that the column supported by the atmosphere in its higher regions ought to be less than that supported near the earth's surface; for as we ascend, the weight of the atmosphere above us diminishes. Pascal was the first to test the truth of this deduction. He took with him a Torricellian tube to the summit of a lofty mountain in France: he found, as he ascended, that the height of the column of mercury became gradually less; and that it rose again as he descended. This result has been abundantly confirmed by subsequent experimenters. De Luc, in a balloon ascent, found the height of the mercurial column to be only 12 inches, his elevation at the time being estimated at 20,000 feet. As is easy to conceive, the mercurial column may be, and indeed has been, actually converted into a means of determining elevations.

We have already described the methods by which the specific gravities of liquids are determined. A new method presents itself to us here, namely, that of weighing the liquid against the atmosphere. Supposing the pressure of the latter to be constant, the heights of the columns supported would be evidently inversely proportional to the specific gravities of the liquids.

2. Two cubic inches of mercury weigh 1 lb., and hence a column of the metal, with a square inch for its

base, and 30 inches in height, would weigh 15 lbs. Thus it is that we infer the pressure of the atmosphere to be 15 lbs. on each square inch of the earth's surface.

3. Arrangements were soon made to read off the height of the mercurial column with greater precision than was deemed necessary on the first experiments. The instrument had a scale attached to it near the summit of the column, and it was quickly observed that the surface of the mercury did not always stand at the same point of the scale. Within certain limits the height of the column varied, thus proving that the atmospheric pressure varied also. In its improved form, the instrument was called a *barometer*.

4. In the reading off of a barometer, the thing to be determined is the difference of level between the mercurial surface without the tube and that within it. It is evident that when the mercury sinks or rises, *both* of these surfaces change their level: now it is a matter of great convenience to be able to bring the surface of the mercury outside to the level of a fixed point, from which the barometer-tube is graduated. To effect this, the vessel v, fig. 14, containing the mercury, is furnished with a moveable bottom, which can be raised or lowered by means of the screw s. A pointed index *i*, of ivory or steel, is caused to depend from the upper portion of the vessel, and before reading off the instrument, the level of the mercury is so adjusted, that the point of the index barely touches the surface. The numbers on the scale denote the heights *above this point*, and consequently furnish us immediately with the difference of level between the two surfaces.

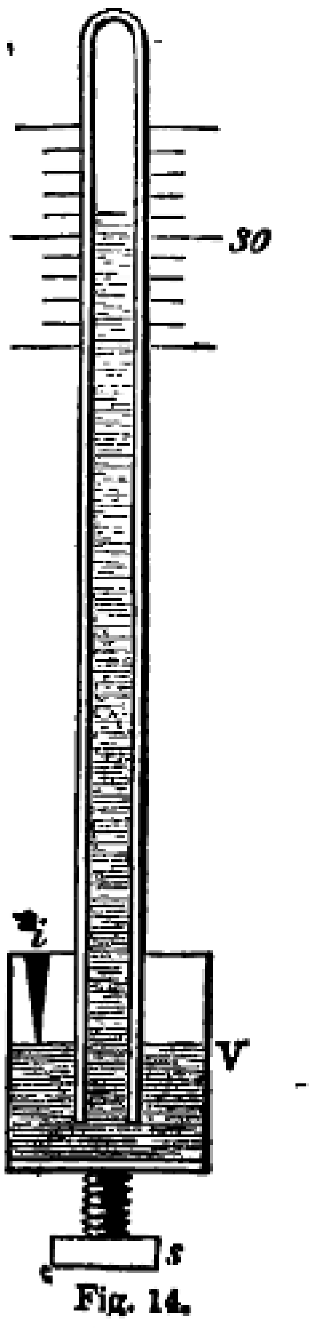


Fig. 14.

In the ordinary wheel-barometer, the fluctuations of the barometric column are transferred to an index which moves like the hand of a clock over the face of a dial. The arrangement will be understood from fig. 15. The glass tube, instead of being immersed in a vessel of mercury, is bent upwards, and the atmospheric pressure on the surface G, sustains the column within the tube. When the atmospheric pressure diminishes, the column falls, and the surface at G becomes elevated. On this surface swims a small adjusted float, from which a string passes over the pulley *p*: when the float is lifted, the weight *w* descends, and draws the pulley round: when the float sinks, the motion of the index is in the opposite direction. It is plain that if the index be long enough, a very small change in the level of the surface at G will produce a very sensible motion of the index.

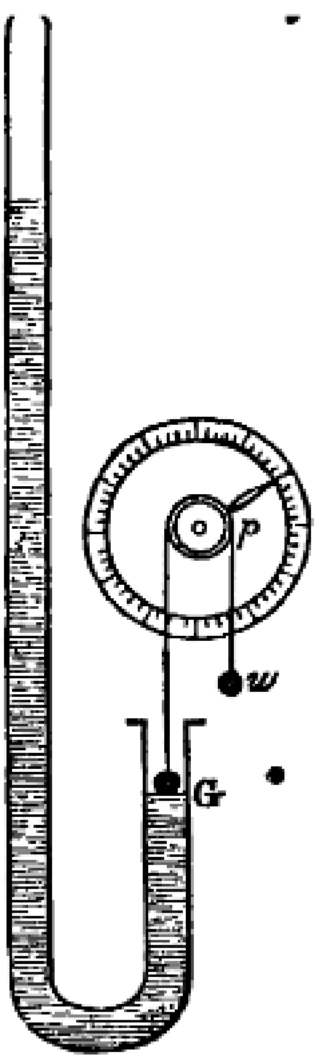


Fig. 15.

5. *How the Barometer may predict Rain.*—The barometer has received the name of the weather-glass; and in the hands of a skilful observer it may indeed be of great value in assisting him to make a close guess at the weather to be expected. Let us examine how this is possible. It is a fact, which we shall have occasion to refer to in our article upon heat, that when air is warmed it swells, and thus becomes specifically lighter. As a consequence of this, the atmosphere in our polar regions is *denser* than at the equator, and when the direction of the wind is from the north or north-east, the superior density of the moving air causes the barometric column to stand high. When, on the contrary, the wind blows from the south or south-west, the moving air conveyed to us from the equatorial regions is comparatively warm and light, and the lightness is accompanied by a corresponding depression of the barometric column. But you may here urge, that this does not explain why the barometer predicts *rain*,

for the direction of the wind has alone been spoken of. Both, however, are connected. It is a well-known fact that the higher the temperature of the air, the greater is the quantity of water which it can preserve in the form of vapour. Hence, if a mass of air, saturated with vapour, be transported from a colder place to a warmer one, the vapour remains uncondensed; but if it be moved from a warmer place to a colder one, condensation takes place, and a portion of the vapour is precipitated as water. Conceive, then, a current of air coming from the south or south-west: it approaches us laden with the vapours which it has contracted in passing over the ocean; but, inasmuch as it moves towards colder regions, this vapour is continually precipitated; and hence it is that the south-west wind brings us such plentiful showers. The wind from the north, on the contrary, has its moisture already precipitated to a great extent, and what it still holds, inasmuch as the air moves from colder to warmer regions, is preserved in the state of vapour: hence it is that the north and north-east winds are usually dry; and thus the barometer justifies, in some measure, its right to the popular name of weather-glass.

6. *How the Barometer may predict a Storm.*—But the barometric column has sometimes been observed to fall suddenly before a storm. Otto von Guerike, whom we shall have occasion to allude to again, predicted, in 1660, from the sudden fall of a barometer during a calm, that a storm must be raging somewhere: two hours afterwards the gale burst upon his own neighbourhood. On the 2nd of August, 1837, the harbour-master of Porto-Rico warned the seamen in the haven that a storm was to be expected, as the barometer had fallen 18 lines in a few hours. The warning was vain: the storm arrived, and of the 33 ships which the harbour contained not one escaped. At St. Bartholmew, 250 houses were destroyed, and at St. Thomas the hurricane carried a 24-pounder cannon along with it. Numerous other instances of a similar nature have been observed.

7. We will now proceed to consider how it is possible that the barometer can foreshow storms in this way.

From the most accurate observations it has been deduced that storms consist of bodies of air rotating round a centre. The little eddies that we observe upon the street, on a dusty day, are examples, on a small scale, of what we mean. Here it will be noticed that the particles of dust are carried round and round, and that, along with this motion of rotation, there is a motion of *translation*, as it is called, of the entire whirling mass from one place to another. In the case of great storms these two motions are also combined; the air whirls with great violence round a centre, while, at the same time, the centre itself is continually carried forward. Imagine a rotating cylinder of air thus impelled: the base of the cylinder, being in contact with the earth, encounters friction and other obstructions, is retarded, and hence the cylinder *leans forward*. The upper portion of the cylinder may, therefore, be over a place long before the bottom has reached it; the storm may be active above, while all is calm below. How then is the pressure of the air influenced by one of these atmospheric whirlpools? Owing to its swift rotation, the air is driven out from the centre on all sides, so that in the neighbourhood of the centre the space is partly *emptied* of air, and consequently cannot support a high barometric column. At the centre itself the depression is a maximum. Reflecting upon these facts, there is no difficulty in conceiving how the barometer may be affected long before the storm has reached it, and thus serve as a valuable warning to those who are able to interpret its indications.

LESSON X.

THE RELATION BETWEEN THE VOLUME AND THE PRESSURE OF ELASTIC FLUIDS.

1. *Law of Mariotte.*—Having learned that air is compressible, our next step is to determine the exact relation between the amount of the compression and the force which produces it. This is done by means of the apparatus sketched in fig. 16. A B C is a bent tube of glass, open at A, and furnished at C with a good

stop-cock. When the cock is open, let a quantity of mercury be poured into A, sufficient to close the bent portion of the tube at B, and to rise to the level of *dd′*, half an inch or an inch above the bent portion. Let the cock C be now closed: we have then a quantity of air enclosed in the space above the mercury surface *d′*, and this is the air which we will submit to compression. Let mercury be poured in at A: as the column in A B heightens, the surface *d′* will be observed to ascend gradually, the air above it being squeezed into a smaller space by the pressure of the mercury. When the volume of air has been squeezed into exactly half its bulk, let the pouring in at A cease. Let the difference of level of the mercury in both arms of the tube be now ascertained: it will be found that this difference is about 30 inches. If A B be long enough, mercury can be poured in at A until the air in B C has been squeezed into one-third of its original volume; we should then find the difference of level in both arms of the tube to be 60 inches. To reduce the air to one-fourth of its volume, a column of 90 inches would be requisite, and so on. But how is it that the increase goes on by additions of 30 inches? Let us consider the state of the air in the tube B C *before* the cock at C was closed. It is evident that it then bore the pressure of the atmosphere above it, which, as already explained, is equal to that of 30 inches of mercury. When the tube A B is filled to a height of 30 inches above the level in B C, it is plain that two atmospheres, as they are called, are pressing on the air in B C. When the height of the pressing column is 60 inches, three atmospheres press upon the air; when 90 inches, a pressure

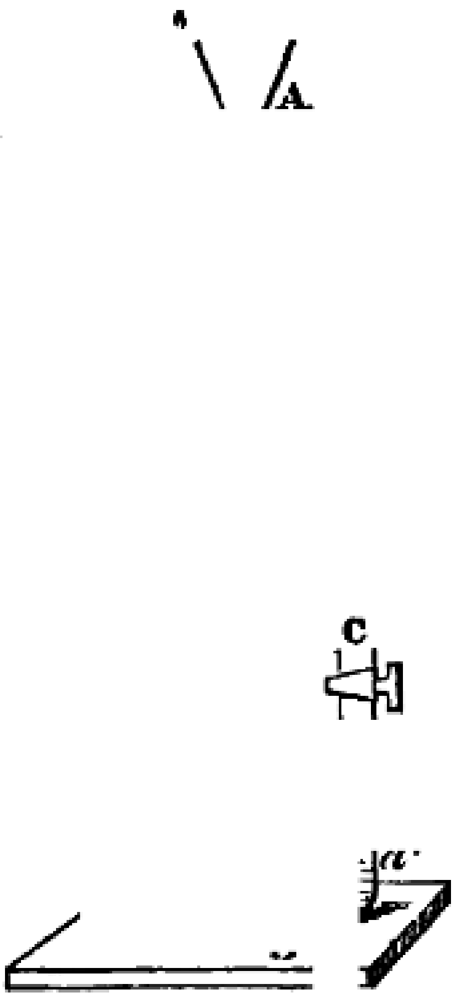


Fig. 16.

of four atmospheres is exerted, and so on. Now, the experiment shows us that by doubling the pressure we reduce the volume of air to one-half, by trebling the pressure we reduce it to one-third, by increasing the pressure four times we diminish the volume four times; and hence we arrive at the important law—a law first discovered by the celebrated Robert Boyle, and rediscovered by Mariotte, whose name it usually bears—that *the volume of a gas is inversely proportional to the pressure under which it exists.*

2. For a long time it was considered that this law was perfectly true for all gases; but it is now known that this is not in strictness the case. When compressed in the manner we have described, some gases are finally reduced to the liquid condition. By cold and pressure, Mr. Faraday has liquified numbers of them. And it is found that those gases which are most easily liquifiable, or which, in other words, are nearest to their points of condensation at ordinary temperatures, exhibit very sensible deviations from the law of Mariotte. Carbonic acid and sulphurous acid are examples of gases of this class; while other gases, amongst which are the constituents of our atmosphere, have resisted all attempts hitherto made to liquify them. With these the law of Mariotte is true to a far greater extent than with the others.

3. To imprint the important principle above established upon the mind, it would be useful to work a few examples in which the law is applied. Want of space prevents us from giving more than one here.

Example 1.—Assuming the law of Mariotte to be true for all pressures, and that water is incompressible; at what depth below the surface of the sea would a bubble of air have the same density as the surrounding water, supposing the weight of the water to be 840 times that of the air at the surface, and that a column of 32 feet of water exercises a pressure of one atmosphere?

What is required here is to know what pressure will reduce a volume of air to $\frac{1}{840}$th part of the bulk it possesses at the surface of the sea, where the pressure upon it is one atmosphere. According to the law of Mariotte, a pressure of 840 atmospheres would accomplish this; and, hence, a depth of 32 feet of water being equal to one atmosphere, it might be thought that we have only to multiply 840 by 32 to find the depth sought. But it must be remembered that the air at the surface already bears the pressure of an atmosphere of air, and to these 839 atmospheres of *water pressure* must be added to make up the 840. Hence, multiplying 839 by 32, we obtain 26,848 feet as the depth sought.

Below this depth, if the above conditions continued to hold, the air would be *heavier* than the water, and would therefore *sink* instead of rise. It must not, however, be forgotten, that the case here supposed is an imaginary one, for water is not incompressible, and it is certain that long before the pressure referred to has been attained, the law of Mariotte ceases to be true.

4. *Further Effects of Atmospheric Pressure.*—In the barometer we see a column of mercury prevented by the pressure of the atmosphere from flowing out of the tube which contains it. If the top of the tube were perforated so as to permit the air to enter, the mercurial column would immediately sink. Such a perforation is made in the lid of a teapot, and if the lid fit tightly, you will observe that the water flows, or ceases to flow, according as the vent-hole is opened or closed. In water-glasses for birds, the liquid within the glass is sustained by the atmospheric pressure; the bird drinks from the bowl *a* (fig. 17), and finally the water within the bowl sinks, until a small bubble of air enters by the tube *b*, and ascends to the summit of the glass; here, by its elastic force, it presses the liquid downwards, and again partially fills the bowl *a*. In this way the process is continued until the whole of the water has been used. The pneumatic ink-bottle is made upon the same principle as the bird-glass: the bowl into which the pen dips is supplied in the same manner as that from which the bird drinks. Many lamps are so constructed that the oil is gradually supplied to the

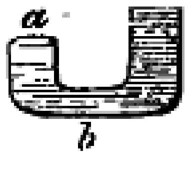


Fig. 17.

wick in the same manner as the water is supplied to the bird, or the ink to the pen.

5. In speaking of the weight of air, we referred to the case of a flask from which the air had been removed: we will now describe how this removal may be accomplished. A sketch of the exhausting syringe is given in fig. 18. C is a cylinder on which the solid piston P moves air-tight; *c* is a cock by means of which the external atmosphere may be admitted to, or shut off from, the space underneath the piston; *d* is a tube furnished with a thread at its lower extremity, on which the vessel to be exhausted, F, is screwed; *e* is a cock by means of which a communication may be established at pleasure between the flask and the cylinder C. The vessel being screwed on, let the cock *e* be opened, and *c* closed. When the piston P is raised, a portion of the air passes from F through *e*, and diffuses itself in the space below the piston. After the piston has reached its highest limit, let *e* be closed and *c* opened; in forcing P down, the air beneath it will escape through *c* into the atmosphere. Closing *c* and opening *e* again, the same process is repeated; at each successive ascent of the piston, a portion of the air is taken from F, and if the pumping continue long enough, it is evident that we can exhaust F almost completely.

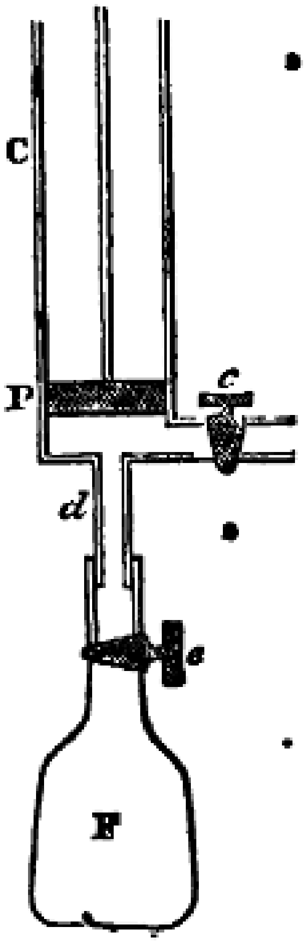


Fig. 18.

We might modify the exhausting syringe by doing away with the cock *e*, and making an aperture through the solid piston, to be closed by a valve opening upwards, as in the case of the common pump.

6. In the *air pump* the exhaustion is hastened by making use of two cylinders, instead of one, the pistons of both being worked by a single winch. The instrument is shown in fig. 19. C C′ are the two cylinders in

which work the pistons P and P′, furnished with valves which open upwards. The pistons are raised by means of

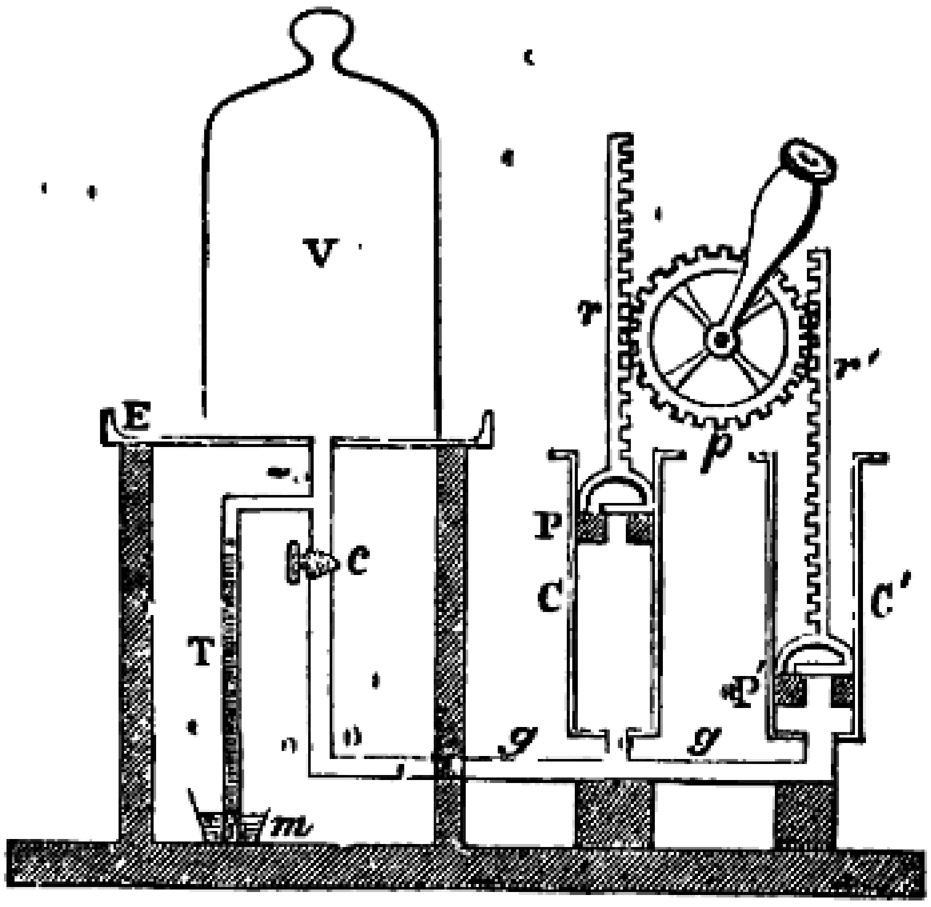


Fig. 19.

two racks *r r′*, and a pinion *p*. A tube *g* connects the cylinders with the vessel V, called a receiver, from which the air is to be exhausted. The edge of V is smeared with lard, to make the junction between it and the plate E air-tight. E is pierced at its centre with an aperture which communicates with the passage *g*. C is a cock which is opened when the receiver is exhausting, and closed when it is required to preserve the exhausted vessel from communicating with the atmosphere. A glass tube T, dipping into a cup of mercury, is usually connected with the passage leading to the receiver: according as the vessel is exhausted, the mercury is forced up in the tube T, and from the height at which it stands we infer the exact amount of exhaustion.

7. *Experiments with the Air-pump.*—If a closed bladder, half filled with air, be placed within the receiver V, as the latter becomes exhausted the air within the bladder swells, and finally quite distends the bladder. A shrivelled apple, under the same circumstances, becomes plump and fresh-looking through the expansion

of the gases within it. When the air is again admitted to v, through a cock provided for this purpose, the bladder collapses, and the apple becomes shrivelled once more. The real substance of wood is heavier than water, and the wood floats, on account of the air within its pores. When a piece of wood, swimming on water, is placed under the receiver, the air escapes on exhaustion from the pores of the wood, the latter consequently becomes heavier, and finally sinks like a brick.

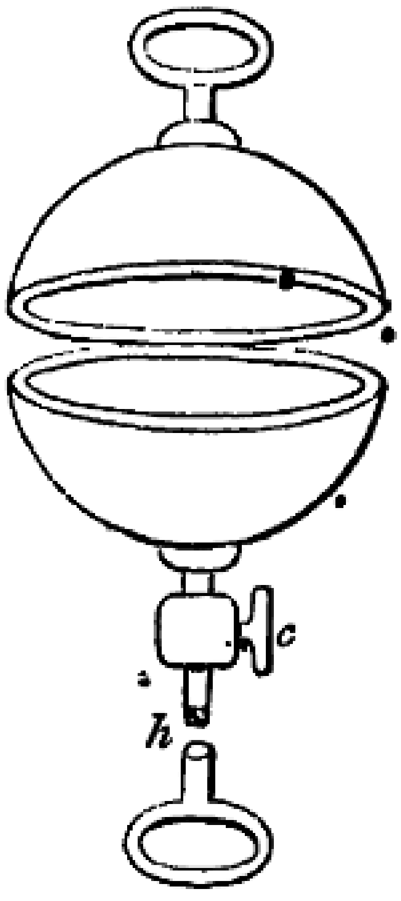


Fig. 20.

8. *Magdeburg Hemispheres.*—But the most celebrated air-pump experiment is that made by its inventor, Otto von Guericke, burgomaster of Magdeburg, in northern Germany. The apparatus he used consisted of two hollow hemispheres of metal, fig. 20. The edges of the hemispheres are fitted accurately to each other, and before the experiment are smeared with lard to make their junction more perfect. From the lower hemisphere a tube issues, which can be screwed into the aperture in the centre of the air-pump plate, and thus the sphere, composed of these two halves, may be exhausted. This being accomplished, the cock *c* closed, and a suitable handle screwed on at *h*, it will be found that two of the strongest boys, each pulling at a handle, will not be able to force the hemispheres asunder; and if they were large enough, the strength of two horses might be exerted for the same purpose in vain. With such force does the external atmosphere squeeze the exhausted hemispheres together! On opening the cock *c*, so as to admit the air, the hemispheres separate without difficulty. The hemispheres with which this celebrated experiment was first made, and which the united strength of six horses was unable to force asunder, are still preserved in the city of Berlin.

LESSON XI.

UNDULATORY MOTION.

1. THERE are few things more pleasant than to stand by the sea on a stormy day, and to watch the billows advancing and breaking in foam upon the shore. Looking at the agitated ocean, we observe a swell at a distance, which comes nearer and nearer, increasing apparently in height as it approaches; the side of the wave next the shore becomes more steep, the crest leans forward, overlaps and falls, sending its foam and spray high up the beach. When we follow the course of a wave in this manner we can hardly resist the belief that the water itself is moving forward; there appears to be a manifest motion from the ocean towards the shore; but if our spectator be an observant boy, he will soon learn that the motion of the *wave* is very different from the motion of the *water*. He watches a sea-bird floating securely among the billows; sometimes he sees it lifted aloft and seated on the summit of a wave, while at the next moment the wave has passed under it and the fowl is in the trough between two waves; he naturally concludes that this could not be if the water were carried onward by the wave. When a boy, I took pleasure in swimming in a rough sea, and when weary with climbing the billows, it was my habit to turn and rest myself by floating. The advancing waves rocked me pleasantly up and down, but they did not carry me forward. This fact now helps me to understand the real nature of the motion which produces waves, and thus illustrates one of the characteristics of natural philosophy. By it the commonest acts of a boy are caused to furnish food for thought; they suggest problems by which his attention is engaged, his knowledge augmented, and his pleasures refined.

2. Let one end of a rope be fastened to a wall or post, and the other end taken in the hand. The rope being held loosely, give the hand a sudden jerk. An undulation will be observed to rush along the rope from the hand to

the other extremity, and by repeating the act, a series of waves may be caused to follow each other in succession. In this case it is manifest that although the waves move forward, the particles of the rope make short excursions to and fro in a direction at right angles to that in which the waves proceed. The case is almost exactly similar with the waves of the sea. If the *water* of the sea moved forward with the *wave*, a fowl seated on the crest of a billow would be carried along with it: the same would occur to a boat or ship; but the fact that both the fowl and the boat are merely affected by an up-and-down movement proves that the particles of water oscillate through a comparatively small space: strictly speaking, in ascending and descending, they move in curves more or less circular.

3. **Reflection of Waves.**—When a stone is cast into

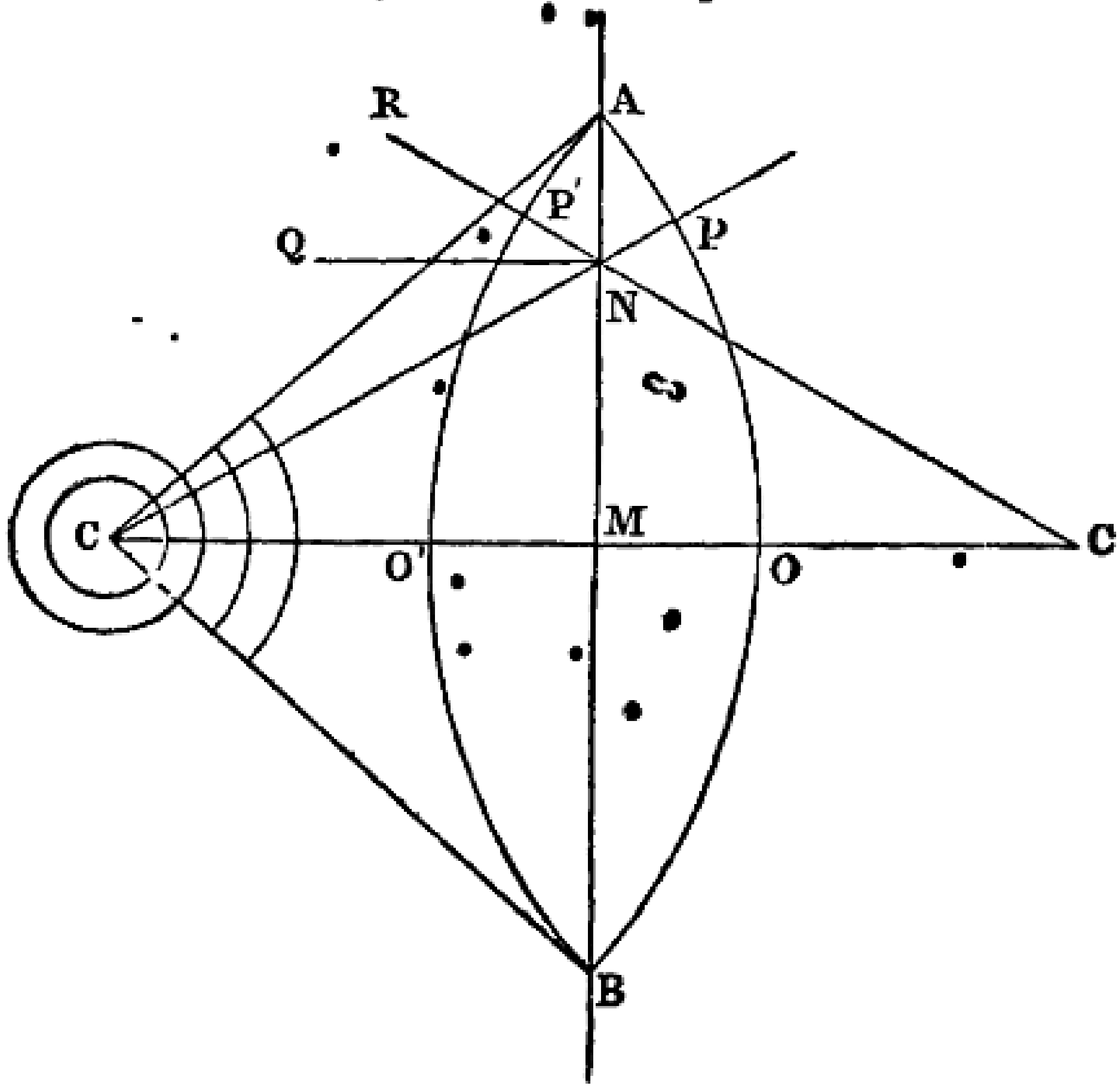


Fig. 1.

a tranquil lake a series of waves spread themselves round the point of disturbance. Supposing C (fig. 1) to be the point thus disturbed, and that the waves propagate themselves to the wall A B, which forms the boundary of the lake. Each ring arrives at the point M of the wall first, and after a certain time it reaches the points A and B also. If no obstacle existed, the foremost part of the wave would reach the point O at the moment the points A and B are attained by the portions corresponding to them. On reaching the point M, however, the wave is reflected, and the ring thus sent back moves with the same velocity as the direct one; the consequence is, that the reflected wave will have reached the point O' in the same time that it would have taken to proceed to O. As each point of the wave successively meets the wall, reflection takes place, and the result is, that the sum of these reflections constitutes a wave A O' B whose centre is at C', as far behind the wall A B as the point C is before it.

4. Let any radius C P be drawn from the centre C to the circumference which the direct wave would have had if it could have proceeded forward; this radius cuts the wall at the point N. Through N let a second radius C' P' be drawn from the centre to the circumference of the reflected wave, and from the point N let a perpendicular N Q be erected to the wall A B. The angle C N Q, which the radius of the direct wave makes with this perpendicular is called the angle of incidence, while the angle R N Q, which the radius of the reflected wave makes with the same perpendicular, is called the angle of reflection. Every boy who knows a little of the first book of Euclid will be able to *prove* that the angle C N Q is equal to R N Q; and even a boy who does not know Euclid will, on reflection, be able to *see* that this is the case. We thus arrive at the important law—a law of the most extensive utility in physics—that *the angle of incidence of a wave is equal to the angle of reflection.* Supposing the wall A B to be a perfectly-hard obstacle, and that a boy shoots against it from the point C along the line C N a perfectly elastic marble, it also would be reflected along the line N R, the law of reflection of waves being the same as that of perfectly-elastic bodies.

5. **Reflection from an Ellipse.**—No matter what the nature of the surface may be, whether curved or plain, this law holds good. There are two curves which possess a peculiar interest in reference to this law, and which we will therefore now describe. The first is the ellipse, which is constructed in the following manner: take two common pins, and with them fasten a sheet of paper to a table, the pins being at the points F F′, say six inches asunder: take a string fourteen or fifteen inches in length, unite its ends and throw it over the pins: with the point of a pencil at P stretch the string, and while keeping it stretched let the pencil be carried round. The curve described by the point of the pencil is an ellipse.

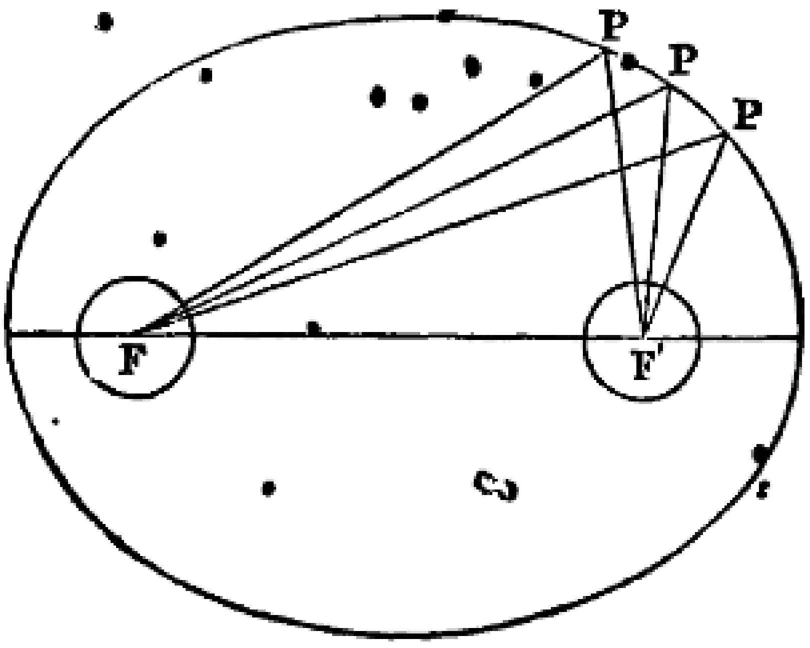


Fig. 2.

6. The points F F are called the foci of the ellipse, and it is a property of the curve that two lines drawn from any point P to the foci make equal angles with the perpendicular to the curve at this point. If therefore we suppose a lake to be of the shape of an ellipse, and that a boy drops a stone into the focus F; the waves proceeding from this focus, when they strike the boundary of the lake at P, will be reflected in the direction P F′ towards the second focus, and around the point F′ will be formed a series of rings like those existing round the point F. This elegant experiment might be made on a small scale with mercury instead of water.

7. **Reflection from a Parabola.**—The second curve is the parabola, which differs from the ellipse in the circumstance that it is not what we call a closed curve: it does not return into itself, so as to enclose a space. The curve is sketched in fig. 3; it possesses a single focus F. The line V M is called the axis of the parabola, and the nature of the curve is such, that when we draw two lines from any point P in the curve, one to the focus F, and the other P *p* parallel to the axis V M,

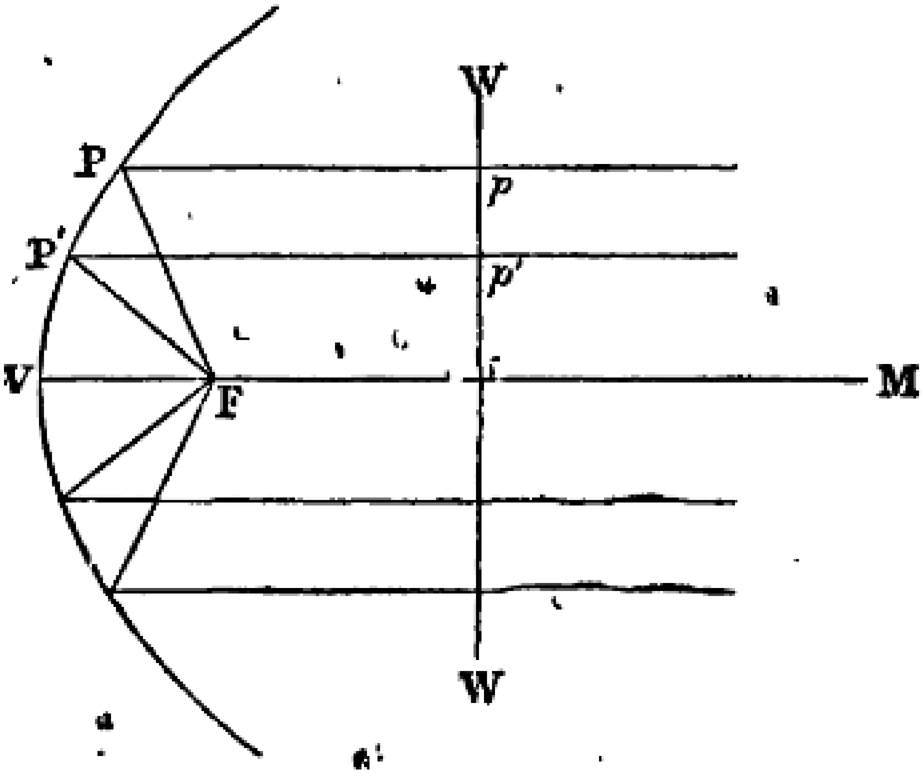


Fig. 3.

these two lines are equally inclined to a perpendicular at the point P. Hence if we suppose a portion of the boundary of a lake to be a parabolic curve, and a stone to be dropped into the lake at the focus, the waves proceeding from this point will be reflected in the direction of the line P *p*. Let W W′ be a line drawn perpendicular to the axis V M, and let us inquire for an instant at what time the various portions of the reflected wave will reach this line. A second property of the parabola is that the two lines P F and P*p*, taken together, are always of the same length, no matter at what portions of the curve the point P may fall. Thus the sum of the two lines P F, P *p* is equal to the sum of the lines P′ F, P′*p*′ or to any other two drawn in a similar manner. The point of the wave reflected from P will therefore reach the line W W′ at precisely the same moment as the point of the wave reflected from P′, for both of them have to travel over the same distance. The consequence is that the reflected wave will present the appearance of a straight line perpendicular to the axis of the parabola.

8. It is quite manifest that if we suppose the wave W W′, instead of proceeding from the curve, to be moving towards it, it would, upon reflection from the surface, retrace its course, and form a circular wave around the focus F. Or, instead of supposing the wave thus to return upon its own footsteps, let a second parabolic reflector be placed in the path of the wave: the series of waves proceeding from the focus of the first reflector, will move forward in straight lines towards the second, and after reflection from it, they will collect themselves in rings around the focus of the second reflector. This arrangement of reflectors is shown in fig. 4.

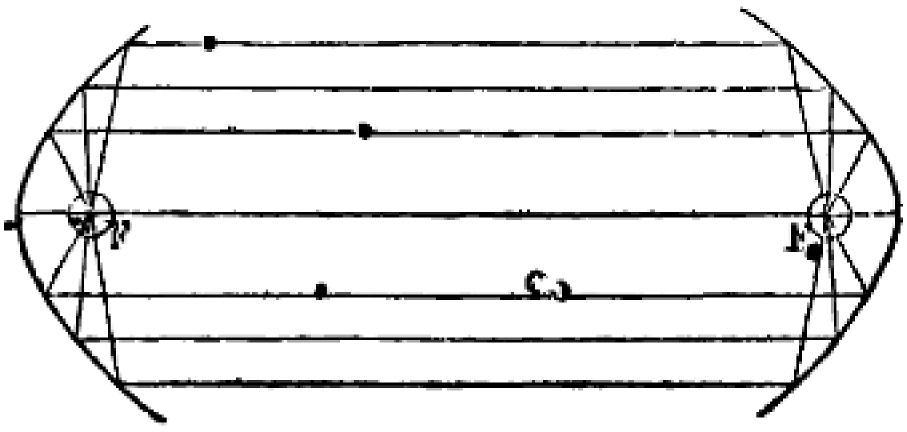


Fig. 4.

9. Interference of Waves.—We now arrive at a point of great importance in wave motion, to which I will briefly direct your attention. Let A B and E D, (fig. 5, p. 82). be two branches of a canal which unite at F to form single channel F C. Let L be a lake which supplies the canals with water, and let a series of waves W W′ advance along the lake towards the canals. Let these waves be supposed to enter A B and E D at the same moment; if the distance from A to F be perfectly equal to the distance from E to F, a particle of water at F will be lifted upwards or depressed downwards at the selfsame moment by the waves from both canals, and the consequence is that the distance

through which the water at F is lifted or depressed will be greater than if only one of the waves acted upon it. Let us now suppose that the two channels A B, E D are not of the same length, and that the difference in length is such that at the precise moment when the *elevations* of the waves from A B reach the point F, the *depressions* of the waves from E D reach the same point. The action of the former would be to *lift* the point F, while the effect of the latter would be to *depress* it: the point F is thus pushed upwards and pulled downwards at one and the same time, and the consequence is that it will move neither up nor down. The waves annihilate each other. The effects which I have thus endeavoured to describe are known under the name of *interference*. The principle of interference is one of the utmost importance in physics, and it will therefore be worth some trouble on your part to comprehend, as far as it is possible from this brief description, the nature of the principle.

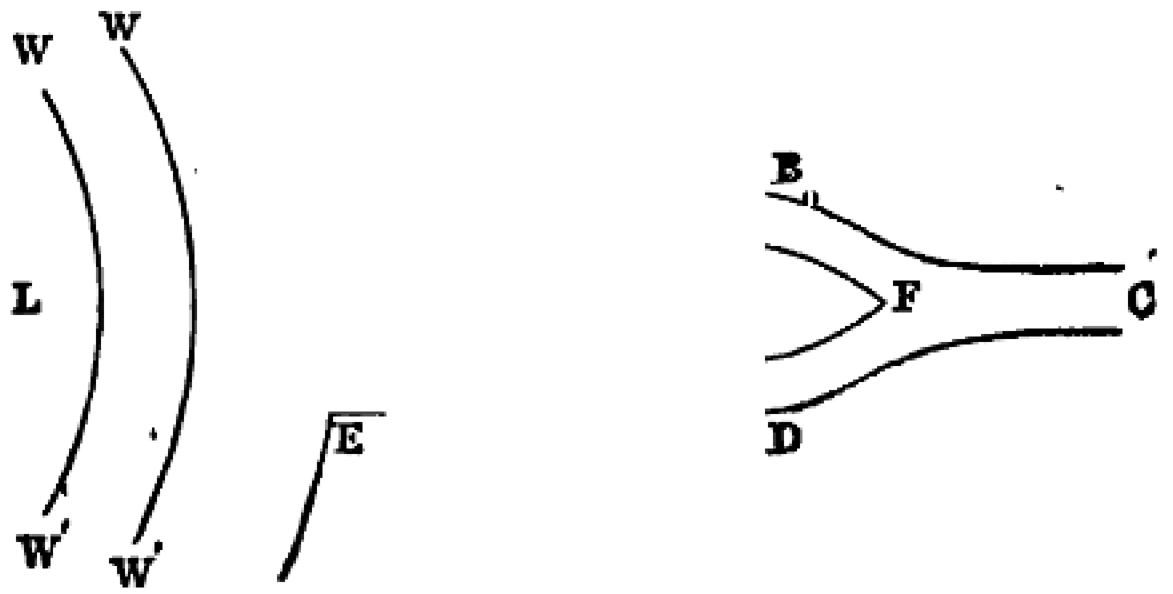


Fig. 5.

10. On the Effects of Oil upon Water.—I think I may, without improperly wandering from the subject of the present article, say in this place, a few words on the remarkable influence of oil upon agitated water, as you will often find, in the works of poets especially, allusions to this subject, which might otherwise be unintelligible to you. Here is an example which just occurs to me:—

> "I pour on life's tempestuous sea
> The oil of peace with thoughts of thee."

The celebrated Benjamin Franklin was once informed by a friend, that the fishermen on the coast of Gibraltar, when they wished to make the surface of the sea smooth, and thus obtain light sufficient to enable them to see the large oysters at the bottom, were accustomed to pour oil upon the surface. On other parts of the Spanish coast the divers carry oil in their mouths, and when they want light they spurt it out; the oil ascends to the surface, spreads over it, and smooths down the ripples which interfere with the entrance of the light. Even in the case of shipwreck, oil has been used to still the water. Mr. Richter, who accompanied a Danish captain to Saint Thomas, stood, during a terrific storm, upon the coast of the island of Santo Porto, and witnessed the wreck and sinking of the ship which had carried him to the island. Immediately after the disappearance of the ship, its boat was observed in the middle of the bay, being driven towards the coast by the storm. When it reached the strand, the sea around the boat appeared to be tranquillized, as if by magic; the white foam disappeared from the surface, and all was still for an instant. Immediately afterwards, however, the billows reared their heads with redoubled force, and *without bursting into foam* flung the boat high upon the strand. Some men sprang out of the boat, and ran up the beach in order to save themselves from being laid hold of by the succeeding wave. It had been the precaution of the captain to carry with him at all times a small cask of oil: this did excellent service in the present instance, and without it a successful landing would have been impossible; for, when the boat was about to be overwhelmed by the breakers at the edge of the bay, the cask was stove in, and the oil poured upon the water—a sudden change of the surface was thereby effected, which was observable from a considerable distance. The oil could not, indeed, render the waves still, but it prevented them from being converted into breakers, and caused them to roll up the beach, carrying the boat along with them to such a distance that its crew were enabled to escape.

11. If you place a piece of silk cloth upon a smooth

table, and push the cloth obliquely with your finger, the cloth yields, and glides over the table, which is thus in a great measure relieved from the effect of the push. So also when water is covered by a layer of oil, which does not cling to it, the oil, acted upon by the wind, glides over the surface of the water, and thus lessens the action of the wind upon the surface. It is true that oil cannot level down the larger waves when they have been once formed, but the sides of large waves are always ridged and furrowed by smaller waves, which render the large ones rough, and thus enables the wind to act upon them with greater power. The oil hinders the formation of these smaller ripples, and by thus lessening the friction it diminishes the effect of the wind. Franklin made some experiments on the effect of oil upon the ponds on Clapham Common. Choosing a time when the surface was ruffled by the wind, he first poured a little oil upon that side of the pond *towards* which the wind blew across the water. Here the waves were largest; but the oil had no effect in rendering the surface smooth. He next went to that side of the pond *from* which the wind blew, and poured a quantity of oil, not exceeding a teaspoonful, upon the surface, which immediately became tranquil for a space of several square yards. This tranquil space extended itself in an astonishing manner, and spread gradually, until it reached the opposite bank of the pond; and thus a surface of half an acre was rendered as smooth as a mirror. On a small scale, Franklin's experiments appeared all to succeed; an experiment, however, which he made on the sea-coast near Portsmouth in 1773 was not attended with equal success.

LESSON XII.

SOUND.

1. WHILE I write these lines the sound of a piano reaches my ear. I hear notes of different kinds, some high, some low, some discordant—for the performer is a boy—and some blending together so as to produce a pleasing harmony. How do these sounds travel from

the piano to me? Why is it that one note is shrill and another deep? Why do one pair of sounds unite to produce harmony while another pair united together produce discord? Surely here is a subject worthy of our efforts to understand it. We will approach it carefully and by easy degrees.

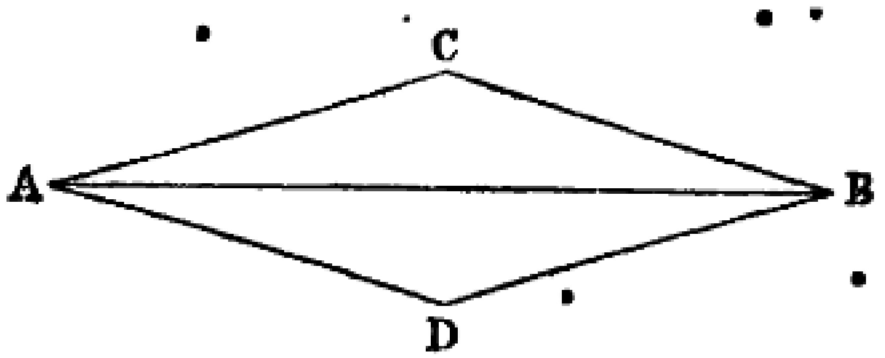


Fig. 6.

2. Vibration of a String.—Let us suppose an elastic string to be stretched between the points A and B, fig. 6. The line A B is the position of equilibrium of the string, or that position in which it will rest, if left to itself. Let the string be taken in the fingers, forcibly drawn aside to C, and then let loose: it will instantly return towards its position of equilibrium, but when it reaches it, it will not stop there. On coming towards the position A B, it has acquired a certain velocity, and on account of its inertia, will pass A B and go on to D at the other side of it. From D it will return again towards C, and thus execute a series of vibrations before it finally comes to rest. The principle is exactly the same as that of the pendulum. If you draw a pendulum aside from the vertical line in which it hangs, and let it go, it will not only return to its position of equilibrium, but will swing beyond it, and will continue so to swing until it is arrested by the friction of the air, or by that of its points of support.

3. Communication of Motion to the Atmosphere.—A string cannot, however, vibrate in our atmosphere in the manner indicated without communicating its motion to the air around it. When the string passes swiftly from C towards D it presses the particles of air in the direction of D more closely together; and on the contrary, when the string recedes from D to C, its effect is to leave the space behind it in some measure

deprived of air. So that the total effect of the string upon the atmosphere is to produce in quick succession condensations and rarefactions of the air.

4. Now, the sound of such a string travels on a frosty day at the rate of 1086 feet in a second. Is it then to be supposed that the air struck by the string is driven over so great a space in so short a time? By no means. We have here a case quite similar to that of waves in water: the particles of air, like the particles of water, make only short excursions to and fro. Sometimes they approach each other, and are for an instant crowded together; they then recede from each other to a certain distance, then close up again, then recede, and so on; the oscillations of each individual particle being thus confined within very narrow bounds.

5. Not so, however, with the undulatory motion of the air thus produced. As the undulations run along a rope when it is shaken by the hand, so each condensation produced by the string moves forward through the air, and is followed by a rarefaction; these are followed by a second and a third condensation and rarefaction, and this effect continues to be produced as long as the string continues to vibrate. One difference, however, exists between the motion of the rope and the motion of the air; the particles of the former oscillate at right angles to the direction of the wave, while the particles of the latter move to and fro in the direction in which the wave is moving. Along the line in which the motion of the vibrating string is propagated we have, therefore, a state of things which may be represented by fig. 7.

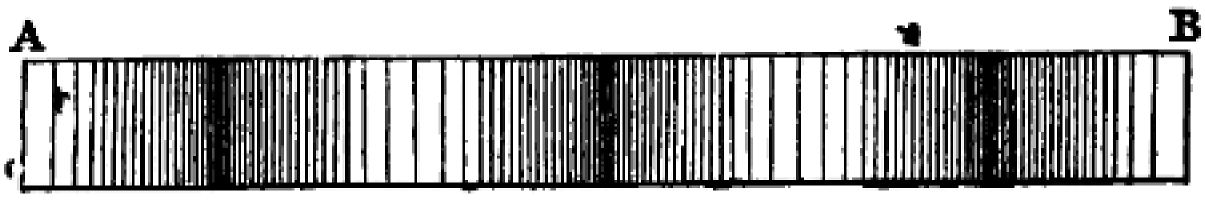


Fig. 7.

Here the portions where the lines are far apart are meant to represent the spaces where the air is rarefied, while the packing of the lines closely together is meant to show the condensed portions of the air. In the case of water a ridge and its adjacent depression constitute a wave; in the case of the undulations, which we are now considering, a condensation and its accompanying rarefaction constitute a wave. In the case of water the length of a wave is the distance between two adjacent summits or furrows; in the present case the length of a wave is expressed by the distance from the centre of one condensation or rarefaction to the centre of the preceding or succeeding one. There are, therefore, three complete waves shown in fig. 7.

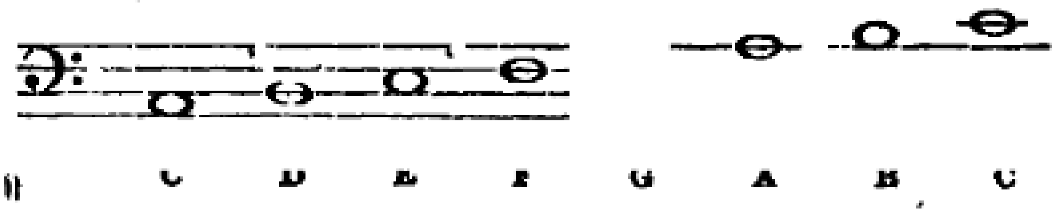
6. Effect of Undulations upon the Ear.—Supposing a stretched membrane—the head of a drum for example—to be placed at D. The waves of air proceeding from a vibrating string, situated in the direction of A, will strike upon the membrane, and throw it into a state of vibration. Now, within the human ear, and drawn across the passage which leads to the brain, there is stretched a tremulous membrane called the *tympanum*, or drum of the ear, from its resemblance to the instrument just referred to. This receives the shocks of the waves of air, transmits them through an appropriate nerve to the brain, and in this way the sensation of sound is excited.

7. On Melody, Pitch, and Harmony.—The famous philosopher Galileo, to whom we have already referred, was once passing through the cathedral of Pisa, when his attention was arrested by a suspended lamp which had been set swinging by the wind, or by some other cause. He observed, as the lamp swung less and less widely, that the time which it required to perform a swing remained the same: an oscillation of short length, or *amplitude*, as it is called, required as much time for its performance as a long one. Reflecting upon this, he was led to the invention of the pendulum as a means of measuring time. The swing upon the playground is a capital instrument for verifying the observation of Galileo. Let a boy swing to and fro through the space of one foot, he will find that this occupies just as much time as when he swings through ten times the distance; at least, the difference of time is too small to be noticed. Now this is exactly the case with our vibrating string; its oscillations become less and less wide, or, in the

language of science, the amplitude of the oscillations diminishes; but it requires the same time to perform a small oscillation as a large one. Hence the waves which it produces are all of the same length; they follow each other at a fixed interval of time, and communicate to the tympanum a regular succession of impulses. The regularity of these impulses produces a *musical sound*—it is the physical cause of melody.

8. This is a very beautiful result, but we will unravel the subject still further. A short string vibrates more quickly than a long one; a light string vibrates more quickly than a heavy one; consequently, by using strings of different lengths or of different thicknesses, we can produce sonorous waves of different lengths. What is the effect upon the ear? It is this; the short waves produce a shriller sound than the long ones. If a string four feet in length be cut in two halves, each half, when it vibrates, will send out twice as many waves in a second as are despatched by the entire string; the note produced by the short string in this case is the *octave* of that produced by the long one. The sole physical difference between a note and its octave is that, in the production of the former, only half the number of impulses reach the ear in a second as are necessary to produce the latter.

9. THE GAMUT; THE MONOCHORD.—We will now examine a little more closely the nature of those tones which come into application in music. The seven successive notes of the gamut may be expressed in musical symbols as follows:—



10. There is an instrument which enables us to tell the lengths of the strings which produce these various notes: this is called a monochord, and is sketched in fig. 8. A string of catgut, or wire, is attached to the fixed point *c*, and supported by two bridges at *f* and *h*: the string passes over a pulley *m*, and is stretched by a weight *p*. Under the string is a hollow sounding-

board, which serves to increase the intensity of the notes; the bridge *f* is moveable, so that by causing it to approach or recede from the fixed bridge *h*, any required length of string may be thrown into vibration.

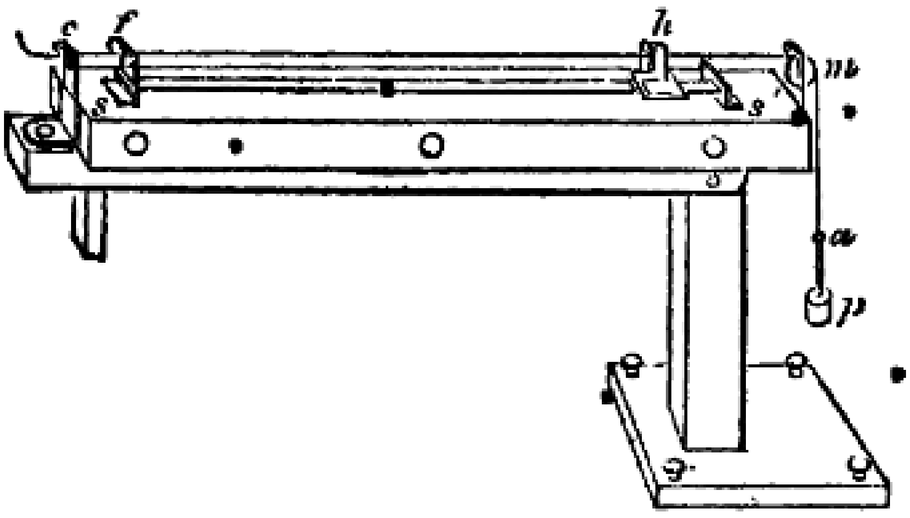


Fig. 8.

11. By means of this instrument let the first note C of the gamut be sounded, and then let the string be shortened until the note D is produced; on measuring the string which produces D we find that its length is $\frac{8}{9}$ths of that which produces the fundamental note C. Let the string be now shortened until the note E is produced; the length of string which produces this note will be found to be $\frac{4}{5}$ths of that which produces C. Shortening the string further, we find that the length which produces the note F is $\frac{3}{4}$ths of that which produces C. In the same way we learn that G is produced by $\frac{2}{3}$rds, A by $\frac{3}{5}$ths, and B by $\frac{8}{15}$ths of the length which produces the note C. Finally, we should find that the second C in the series is produced by a string whose length is one-half of that corresponding to the fundamental note: the second C is the octave of the first.

12. Calling then the length of string which produces the fundamental note C, unity, the lengths which correspond to the seven notes of the gamut are expressed as follows:—

C	D	E	F	G	A	B	C
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

Now it is a law of musical vibration that the number of vibrations performed in a given time increases exactly in proportion as the length of the string diminishes;

or, in other words, the number of vibrations is inversely proportional to the length of the string. Hence, if the number of vibrations corresponding to the fundamental note C be expressed by unity, by simply inverting the above fractions we obtain the proportionate vibrations corresponding to the seven notes of the gamut, viz:—

C	D	E	F	G	A	B	C
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

13. These numbers simply express the *proportion* which the vibrations corresponding to the various notes bear to each other. It is manifest that if, instead of expressing the number of vibrations corresponding to the fundamental note C by 1 we express it by 8, the numbers corresponding to the other notes must be increased in the same proportion. The octave, for example, would then be 16 instead of 2; the note E would be 10 instead of $\frac{5}{4}$ths, and so on. By multiplying the whole series by 24, or in other words by expressing the number of vibrations corresponding to the first C by 24, we clear the series entirely of fractions, and find the following numbers as expressive of the vibrations necessary to produce the seven respective notes of the gamut:—

C	D	E	F	G	A	B	C
24	27	30	32	36	40	45	48

The second C, as we have stated, is the octave of the first: should it be required to find the number of vibrations corresponding to the octaves of the other notes, we should simply have to multiply the number of vibrations corresponding to each of those notes by 2. Thus 54 would be the number answering to the octave of D; 60 would answer to the octave of E, and so on.

If, therefore, in any given time the string producing the fundamental note C, make 24 vibrations; the string producing the note D will make 27; that producing the note E will make 30; that producing F, 32; that producing G, 36; that producing A, 40; that producing B, 45, and that producing the octave C, 48 in the same time.

14. But why are these particular notes chosen for the gamut? The answer is, that in combination they produce the most pleasant impressions upon the ear: this leads us to consider what it is that makes one pair of notes harmonious, and another pair discordant.

If we inquire which are the notes that sounded simultaneously with the fundamental note C will produce the most agreeable sensation, we shall find them to stand in the following order:—

First, the octave, which makes the most perfect harmony: this impression is produced by two series of waves, each wave of one series being twice the length of the other. Every second wave of the octave strikes the ear at the same moment as the wave from the fundamental note C.

Secondly, the fifth; this is produced when the fundamental note C is sounded with G. By reference to the row of proportionate vibrations, at paragraph 12, it will be seen that three vibrations of G are performed in the same time as two of C. Hence a wave from G enters the ear with every second one from C.

The next harmony is that of the fourth, which is produced when C and F are sounded together. By reference to the proportionate vibrations, we find that four of F's vibrations are executed in the same time as three of C's. Here therefore we have a coincident vibration at the commencement of every third vibration of the fundamental note C.

The harmony next to the fourth is that of the third, which is due to the simultaneous sounding of the notes C and E. Referring again to paragraph 12, we find that for every four vibrations of C we have five of E. The coincidences in this case are therefore at every fourth vibration of the fundamental note.

15. Thus we find the two facts constantly accompanying each other: the more frequent the coincidences the more perfect the harmony, and hence it is fair to infer, that these coincidences in vibrations are the true physical cause of harmony. When the coincidences become less and less frequent we soon merge into discord, and where a number of waves of different

lengths strike in an irregular and confused manner upon the ear, the impression of harmony is completely destroyed, and we are sensible of mere *noise*.

16. INTERFERENCE OF SOUND.—We have already referred to the *interference* of waves formed in water, and a little reflection enables us to conceive of the possibility of two waves of air encountering each other so that they shall mutually destroy each other. Let us suppose the condensed portion of one wave and the rarefied portion of another to reach the same spot at the same moment. During condensation the direction of the motion of the particles of air is opposed to that during rarefaction, hence the possibility that while one wave may tend to cause the particles to *close up*, a second wave may tend to cause the same particles to *open out*, and that acted upon by these two opposing forces the motion of the particles may be quite destroyed. Each of the waves taken separately would produce sound, but acting together they produce none, and thus we arrive at the singular conclusion that by adding sound to sound we can produce silence. It is worthy of remark that a similar effect can be obtained with rays of light; by adding light to light it is possible to produce darkness. This fact has led to the modern belief that light is caused by undulations, and not, as Newton supposed it to be, by the darting off of little particles from the luminous body. Recent investigations have proved that a similar result can be obtained with the rays of heat; by adding heat to heat it is possible to produce cold, and this fact among others, has led philosophers to believe that radiant heat is also the product of undulatory motion.

LESSON XIII.

1. MODES OF DETERMINING THE ABSOLUTE NUMBER OF VIBRATIONS OF MUSICAL NOTES.—We have thus far confined ourselves to the consideration of the proportion which the vibrations corresponding to the seven notes of the gamut bear to each other. But supposing that we hear a certain tone—the shrill voice of an opera singer, for example—is there any means by which we

can ascertain the absolute number of vibrations to which this tone is due? Can we by any mechanical means count the number of impulses imparted by the vocal organs of the singer to the atmosphere in a second of time? We can. Let a strong wooden disk about seven inches in diameter be weighted by a coating of lead, and upon this disk let a second disk of thin pasteboard, a foot in diameter, be placed. Let the rim of the latter disk be pierced with round holes, each about two lines in diameter, and exactly the same distance apart all round: the disk thus prepared will present the appearance shown by fig. 10. Let this disk be placed upon the vertical axis of a whirling-table and caused to rotate. Let a glass tube of a diameter somewhat less than that of the holes in the pasteboard be so fixed that when the disk rotates the holes shall pass one after another exactly underneath the end of the glass tube. Supposing now that a person blows constantly through the glass tube, and that the number of holes in the disk is twenty, it is manifest that every time the disk goes once round twenty puffs will escape through the apertures. By causing the disk to revolve quickly, a musical note will soon be heard, which increases in height as the disk increases in velocity. Let the singer whose voice it is our intention to examine be placed near the instrument, and let the velocity of the disk be augmented until it sounds the same note as that sounded by the singer. The number of impulses imparted by both to the air will then be the same, and knowing the number of times the handle of the whirling-table is turned in a second, we can readily calculate the number of vibrations.

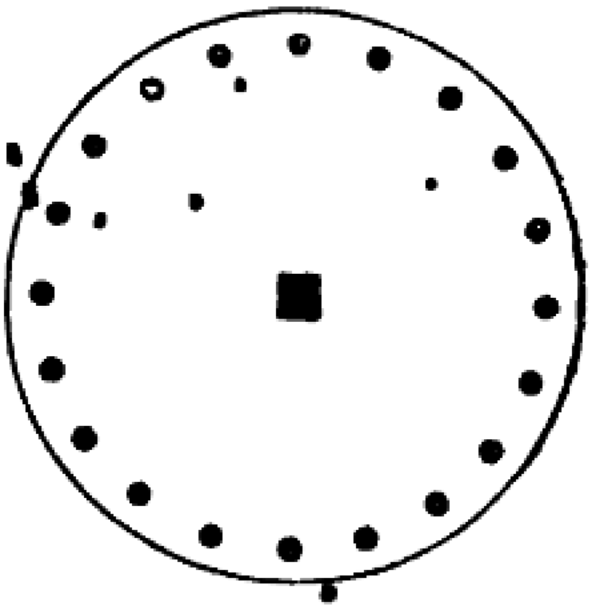


Fig. 10.

Suppose, for example, that the disk when brought to the pitch of the voice, makes one hundred revolutions in a second: for each revolution we have twenty impulses, and consequently one hundred times twenty, or two thousand impulses in a second, will be the number produced by the singer.

In like manner if we compare the sound of our rotating disk with that of a vibrating, string we shall find that if a string, which produces a certain note be cut in two, to produce the note of the half string the disk must move with twice the velocity necessary to produce the note emitted from the whole string. If our disk be furnished with a second series of holes ten in number, and the note produced by blowing a stream of air against the series of ten, be compared with that produced by blowing against the series of twenty, it will be found that the latter note is the octave of the former.

2. **The Syren.**—This simple description will render plain to you the principle of a very beautiful instrument called the Syren, which was devised many years ago by a French philosopher, named Cagniard de la Tour. A circular brass vessel, *ff′* (fig. 11), is closed at the top by a smooth plate *v v′*: from the bottom of the vessel issues a tube *y y′*, through which air can be forced from suitable bellows into the vessel *ff′*. The plate *v v′* which covers the vessel is perforated with holes near its circumference. Above this plate is another, *u u′*, which is supported with such delicacy that the least impulse causes it to rotate. This plate is also pierced with the same number of holes as the under one, but, instead of being drilled perpendicularly through the plate, they are cut through obliquely. A plan and section of the plate are given in fig. 12. Supposing the holes in the upper plate to coincide with those of the under one, the air from the bellows will be forced through: but in passing through the oblique holes it

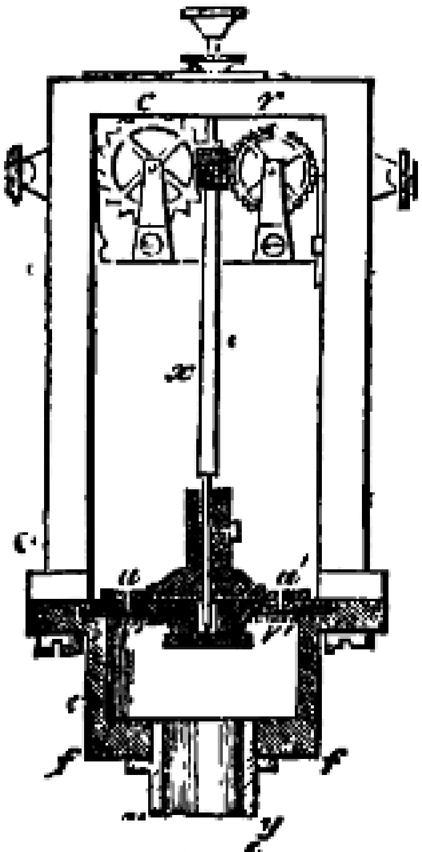


Fig. 11,

is manifest that part of its force will be expended in causing the upper plate to rotate, and by this artifice the plate is set in motion without a whirling-table or any other special apparatus. As the upper plate rotates, the air from the vessel beneath is alternately cut off and permitted to escape; when the holes below coincide with those above a puff escapes, but when they do not

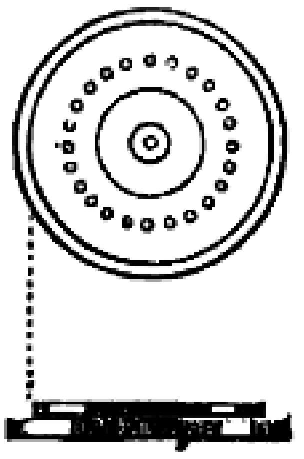
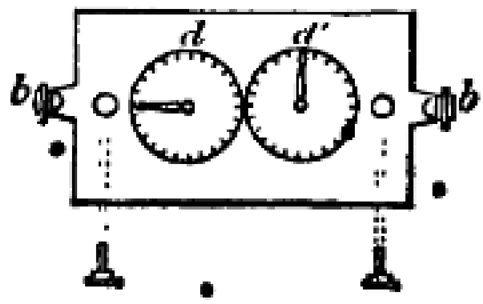


Fig. 12.



coincide the current is interrupted. The puffs thus escaping create undulations in the air, and when these are quick enough they produce a musical sound. By a little tact with the bellows the motion of the upper disk can be preserved uniform, and then we have a uniform note; by working the bellows vigorously, the velocity of the upper disk is increased and the note heightened.

Connected with the disk, and rotating along with it, is an axis x, and on this axis is a worm or endless screw, which imparts motion to a little clock-work mechanism above, and causes the toothed wheels *c* and *r* to rotate. Attached to the axes of these wheels are two indexes or hands which move over dials, such as are shown in fig. 13: one dial tells us the number of single revolutions, while the index of the other wheel moves forward one division every time a hunded revolutions are accomplished. Hence supposing after the lapse of a second's rotation the index of the latter dial stands at the number 5, and that of the former at the number 20, we should know the number of revolutions accomplished in a second to be 520, and multiplying this number by the number of perforations in the disk, we obtain the number of waves despatched by the disk in a second. This instrument has been recently modified by M. Dove, of Berlin: one at present in my possession has four series of apertures. The series nearest the centre has eight holes, that nearest the circumference sixteen, the other two have ten and twelve apertures respectively. When the disk is in motion the outer series sounds the octave of the inner one, C, while the notes sounded by the other two series are those marked E and G in the gamut.

3. Supposing one hole only to be in the under plate, and that only one series of holes are used, we should have a case exactly similar to that first described, where a single stream of air from a glass tube was projected against a pasteboard disk. This single hole would produce the same note as that produced when the number of perforations in the lower plate is equal to that in the upper one. But the sound would not be at all so intense: by letting a puff escape from ten or twelve holes at the same time its action upon the ear is much more powerful than could be produced by the puff from a single aperture. I must warn you here against confounding *pitch* and *intensity:* the pitch depends solely upon the *number* of the puffs; while the intensity depends purely upon the *force* of the puffs. When all the holes in the upper disk correspond to those in the under one, the issue of air through all must be regarded as a *single puff*. The multiplication of the holes of the under disk increases the force of the puff, but as it does not increase the number of puffs, the pitch is just the same as if only a single aperture were used.

4. There is still another instrument made use of to determine the number of vibrations due to any particular note. It is based on the principle that a succession of taps, if they follow each other with sufficient rapidity, unite together to form a musical note. The instrument is sketched in fig. 14: *a a* is a solid frame which supports the large wheel *b*; from this wheel motion is communicated by a band *x*, to a toothed wheel *d*. The teeth of the latter are caused to strike against a piece of card or other suitable substance. The successive shocks given to the card are imparted by it to the atmosphere, and when the velocity of the wheel *d* is small, a succession of taps merely is audible.

When, however, the velocity increases, the taps appear to unite together and produce a continuous note, the

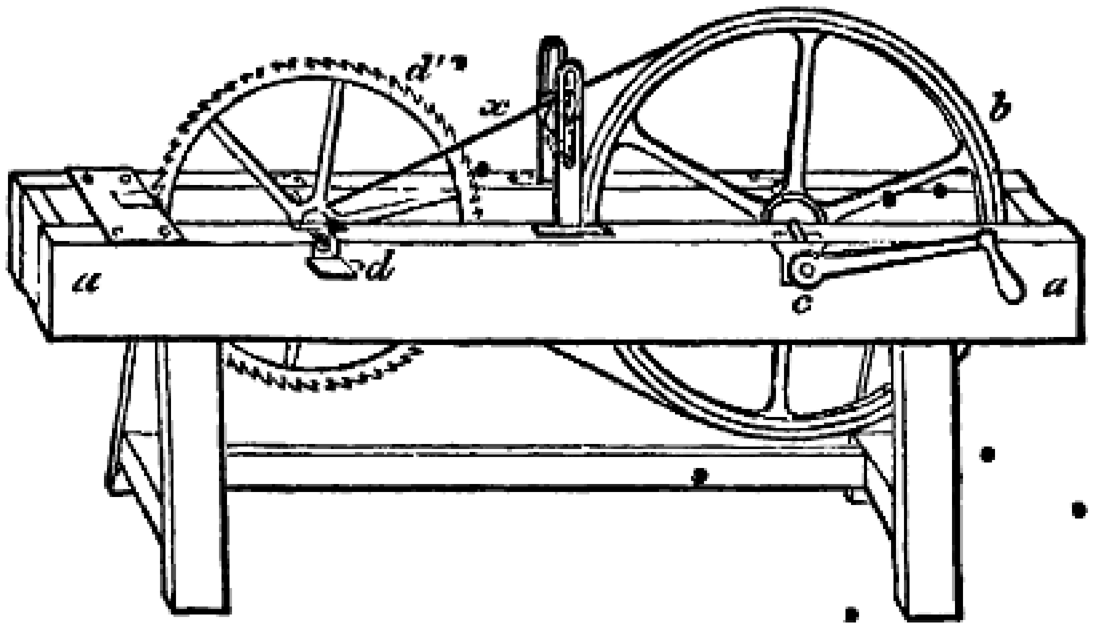
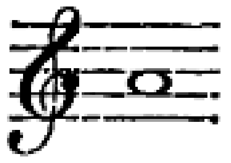


Fig. 14.

pitch of which is determined by the rapidity with which the card is struck by the teeth of the wheel. When we know the number of times the handle has gone round in a second, and also the number of teeth in the wheel *d'*, we can readily calculate the number of taps given to the card in a second of time. With either this instrument or that of Cagniàrd de la Tour we can produce a note of the same pitch as that produced by a musquito, a gnat, a bee, or a beetle, and thus infer with the greatest accuracy the number of times that the insect claps its wings in a second.

5. By experiments with these instruments it has been ascertained that the lower A of the treble clef, written thus by musicians,  is produced by vibrations whose rate of production is 440 in a second. Knowing the number of vibrations performed in a second, it is very easy to calculate the length of the corresponding waves of air. We know, for example, that in a second of time, sound passes over a space of 1120 feet, hence, in the case of a string which vibrates say 440 times in a second, at the moment when the string makes its 440th vibration, the first wave is already 1120 feet distant; in the space therefore of 1120 feet, 440 waves must exist, and hence to find the length of one wave we must divide 1120 by 440, and find the quotient to be 2½ feet nearly. Again,

let it be required to determine the length of the waves produced by a gnat which flaps its wings 13,000 times a second. Here in the space of 1120 feet we have 13,000 waves. Reducing the feet to inches, and dividing by 13,000, it will be found that the length of each of these waves would be one inch nearly.

6. There is a tone which marks the limit of the power of the human ear, and beyond which its power of hearing fails; this limit is fixed at about 24,000 undulations per second; beyond this the sound becomes so thin and shrill that it vanishes altogether. It is perfectly possible however that there are animals possessing organs capable of appreciating sounds which are quite inaudible to human ears. To ascertain the number of vibrations corresponding to the deepest note of which the human ear is sensible, M. Savart devised the apparatus sketched in fig. 15. Here, instead of the toothed wheel *d′* in fig. 14, a single bar was caused to revolve, and at one point of its revolution it came very close to two plates of wood placed on opposite sides of it. It did not strike the plates of wood, but a minute interval, sometimes not more than the 8000th part of an inch, existed between the plates and the bar where it passed them. At the moment of its passage, however, a deafening sound was emitted; and when the velocity was slow, these explosions, for they might be called such, were heard in succession. But when a velocity was imparted to the bar sufficiently great to produce eight shocks a second, the sound became continuous, and a deep musical note was heard, of such intensity that it drowned all ordinary sounds. A note corresponding to eight impulses per second is the gravest of which the human ear has as yet been rendered sensible.

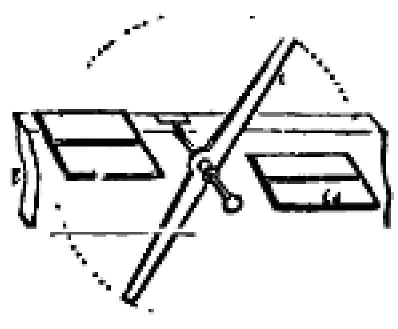


Fig. 16.

7. ON THE REFLECTION OF SOUND.—We have already learned that liquid waves striking against a surface are reflected according to a certain law: the same law holds strictly true of the waves of sound. This reflection is the cause of echoes. Supposing the air to be in

such a state that the velocity of sound is 1120 feet in a second; if a boy stand at 560 feet distance from a high wall and shout, the impulse travels through the air, is reflected from the wall, and reaches the ear as an echo, one second after the boy has shouted. I say one second, because the wave has had to travel first from the boy to the wall, and secondly from the wall back to the boy, in all a distance of 1120 feet. If instead of standing before a single wall, a boy stand between two walls, he will have an echo from each of them; if the boy stands midway between the walls, both echoes reach him at the same instant, but if nearer to one wall than to the other he hears the echoes in succession, the reflection from the distant wall reaching him latest. It is manifest that the wave proceeding from one of the walls may travel on to the other and be reflected there a second time, and that in this way echoes may be multiplied. Between the towns of Coblentz and Mayence the river Rhine makes its way between high precipitous cliffs. Between these cliffs an enchantress named the Lurlei is said in former ages to have sung, and by enticing vessels on to the rocks and shallows of the river, caused disastrous shipwrecks. Sometimes when the steamers from Rotterdam pass between these precipices, a man comes out of a little hut by the river side and fires a gun. The echoes sound from side to side like the rumbling of thunder, and at this place the echo has been found to be repeated seventeen times. There is a chasm among the Hartz mountains, where a gun is fired and a similar effect produced: in mountainous districts indeed this effect is very common. I once met a hunter on the Wengern Alp in Switzerland, right opposite to the Jungfrau mountain: he sounded an Alpine horn, and its sound, reflected from the sides of the mountains, returned to us, first strong, then by degrees feebler and softer, until finally it died away in delightful tones which resembled the notes of a flute sounding from the distant solitudes of snow. A single shepherd's boy, sitting on a crag and performing the so-called *Jodel*, can fill a ravine with the most wonderful melody, owing to the multiplication of echoes from the surrounding rocks and mountains.

8. If we speak through a tube, the sound, instead of diverging into the atmosphere, is reflected from the sides of the tube, and in this way a far greater body of sound may be sent to the ear than by the unaided voice. This is the philosophy of the speaking-trumpet. Gutta percha tubes are very much used at present to convey sounds from one portion of a building to another. Some time ago I stood near a friend in Manchester while he sent a whisper to a servant in the kitchen, which was twenty or thirty feet distant; the whisper was promptly responded to, although I, standing at a distance of three feet from my friend, heard nothing. The ear-trumpet presents a wide mouth to the rays of sound; while its narrow end is caused to enter the ear. In this way a greater number of these rays are collected by reflection than would otherwise reach the ear. In the whispering gallery of St. Paul's a speaker stands at one end of the diameter of the circular gallery while the person who hears stands at the opposite end with his ear to the wall. The wall is quite smooth and the whisper is reflected by it on both sides, the reflected impulses meeting at the point in which the hearer is placed. The law of reflection of waves of air is precisely the same as the law for liquid waves: the angle of incidence is equal to the angle of reflection. If a sound be produced at one focus of an elliptical reflector it will be collected together at the second focus. In like manner, if we make use of the pair of parabolic mirrors already described, the ticking of a watch placed in the focus of one mirror is distinctly heard at the focus of the other, while when the ear is drawn aside a little from the focus the ticking ceases to be audible.

9. **Sound affected by the state of the Air.**— If the air were cut away no sound would be possible; an explosion under the receiver of an air-pump is not heard unless the sound be transmitted through the solid parts of the pump. Even when the air is much rarefied the sound is much weakened. A man's voice on high mountain summits, where the air is thin, is feebler than in the valleys; and the sound of a pistol fired by

Saussure on the summit of Mont Blanc was not louder than that of a common cracker. The intensity of the sound grows less as we ascend, but strange to say the velocity of sound on the tops of mountains is just the same as in the valleys. This of course is a mere puzzle when we do not understand it, but when it is understood it is very beautiful. It is, indeed, the character of science to confer beauty and interest upon facts which would otherwise possess no more value for us than for the dog or the horse. It would be far from wise to shut out the beauty which natural philosophy reveals to us, and to seek to restrict it to the satisfaction of those necessities which we possess in common with animals. Natural science, indeed, helps us to do the latter, but it does more, by appealing to faculties which man alone possesses, by exercising his intellect, and filling him with sweet joy, in the recognition of beauty and order in the creation.

The velocity of sound depends upon the elastic force of the air. Hot air is more elastic than cold, and hence, on a warm summer's day, sound travels more quickly than in winter. When the air is at a freezing temperature—that is, at a temperature of 0° on the centigrade, or of 32° on the Fahrenheit thermometer, the velocity of sound is, as before stated, 1086 feet a second. At a temperature of 10° C. or 50° Fahr., the velocity is nearly 1107 feet a second. The velocity of sound depends, however, not only upon the elastic force of the air, but also upon its weight. Fig. 16, upon the margin, is the same as that used to demonstrate the law of Marriotte, at page 317 of the Second Book of Lessons: referring to this page, you will be reminded, that when the air has been squeezed into half its bulk, it presses with a double force upon the sides of the tube which

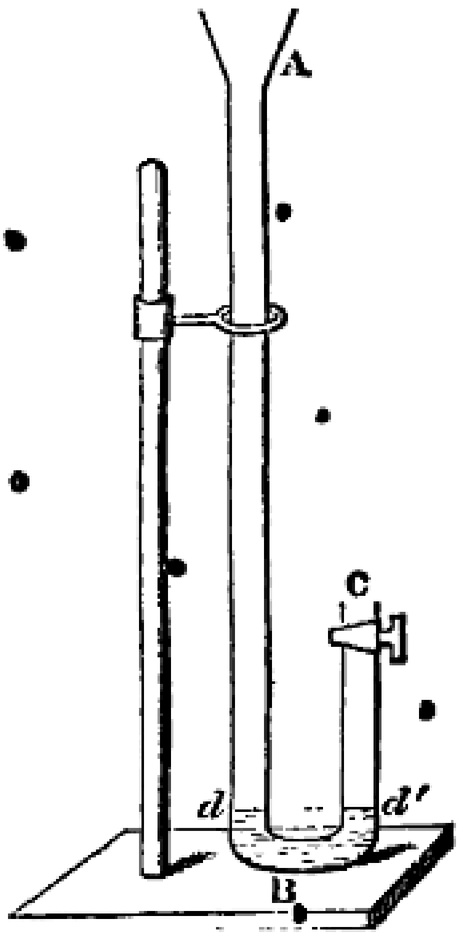


Fig. 16.

contains it; if it be reduced to one-third of its volume, it presses with a treble force against the sides of the tube, and the pressure thus exerted is a measure of the elastic force of the air. Now we have said that the more elastic air is, the more quickly will sound travel through it, and hence you might be disposed to conclude that sound, passing through this air, with its elasticity increased by pressure, will proceed at a higher velocity than through uncompressed air. But remember, that in this experiment we have done more than increase the *elasticity* of the air; we have also augmented its *density*, and we find that while the elastic force has become greater, the amount of matter to be set in motion has increased in precisely the same proportion. The additional weight exactly neutralises the additional elasticity, and sound will not, therefore, travel more quickly in such condensed air than in uncondensed. It is thus with the atmosphere, except when heat, which adds nothing to weight, is the cause of its increased elasticity. The elastic force at the surface of the sea is certainly greater than at the summit of a mountain; but the weight of the air is greater in the same proportion, and hence sound travels as quickly above as below.

10. VELOCITY OF SOUND IN DIFFERENT SUBSTANCES. —The velocity of sound is different in different substances. In alcohol its velocity at 10° C., or 50° Fahr., is 3796 feet in a second; in water of the same temperature it is 4767 feet a second, and in saturated water of ammonia it is no less than 6044 feet a second. In solid substances the velocity of sound is still higher: through mahogany and elm its velocity is upwards of 14 times its velocity in air; through iron and steel it travels with nearly 17 times its speed through air. If a boy place his ear at one end of a long beam of timber, while another boy scratches the opposite end with a nail or pin, it is surprising with what distinctness the sound will be heard. If one end of a long iron railing be struck with a hammer, an attentive boy standing at the other end will hear the sound of the stroke *twice*. The sound travels through the metal and through the air at the same time, but through the former it reaches the ear first, and this is the reason why the shock is heard double.

LESSON XIV.

1. In conclusion, I will write down a few questions which will cause you to think on what I have written, and thus impress it upon your mind. In all the questions I will suppose the velocity of sound in air to be 1120 feet in a second.

Question 1.—The flash from a cannon fired from a vessel at Spithead is observed by a person on shore at precisely 3 o'clock in the afternoon; he hears the report at 1 minute 32 seconds past 3. What is the distance of the ship from the observer, the passage of light over this distance being supposed to be sensibly instantaneous?

Question 2.—The report of a gun fired in the dockyard at Portsmouth reaches an object at Gosport 5200 feet distant, from which it is reflected at a right angle. The sound thus reflected reaches the ear of an observer standing 4 miles distant from the object; and who has previously heard the sound proceeding direct from the cannon. The direct sound being heard at noon, at what o'clock will the echo reach the observer?

Question 3.—An iron water-main, 3 miles long, receives a blow at one end; the shock is transmitted to the other, and then communicated to water, through which it is propagated for a distance of 2 miles: it afterwards passes through 1 mile of air to an observer: required the time of its passage from beginning to end?

2. To prepare you for some of the following questions, I must make you acquainted with certain important laws, which have been established by experiments made with the monochord described in paragraph 10, page 250.

a. When two strings of the same thickness and material, but of different lengths, are stretched by the same weight, the rates of vibration, as already stated, are inversely proportional to the length of the string.

b. Two strings of the same length and material, but of different thicknesses, being stretched by the same weight, the rates of vibration are inversely proportional to the diameters of the strings. If one string, for example, be three times as thick as the other, the number of vibrations executed by the thick string in a second will be only one-third of the number executed by the thin one.

c. Two strings of the same length, material, and thickness, being stretched by different weights, the rates of vibration are directly proportional to the square root of the stretching force. Thus if one string be stretched by a force of 4 lbs. while the other is stretched by a force of 9 lbs., the rates of vibration of these two strings will be as the square root of 4 is to the square root of 9; or as 2 : 3.

Question 4.—A string 4 feet long, and stretched by a weight of 14 lbs., sends out 840 undulations in a second: to what length must we reduce this string, so that the number of undulations despatched in a second shall be 4620? This is solved by law *a*.

Question 5.—A string of catgut $\frac{1}{16}$th of an inch in thickness vibrates 964 times in a second: another string of the same length, and stretched by the same force, accomplishes 4820 vibrations in a second: required the diameter of the latter string? This is solved by law *b*.

Question 6.—Two strings of the same material and thickness, one 4 feet and the other 16 feet in length form successive monochords: the first is stretched by a weight of 12 lbs.: with what weight must the long one be stretched, so that both strings shall sound the same note? This is solved by law *c*.

Question 7.—Required the lengths of the waves corresponding to the lowest note of which the human ear is sensible: the rate of undulation being that stated in paragraph 6 page 98.

Question 8.—The length of the undulations produced by an insect's wing being three-quarters of an inch: it is required to calculate from this the number of times the insect flaps its wings in a second.

There is no difficulty in devising such questions as the foregoing; and they will be found a most instructive and entertaining exercise for the pupil.

HEAT.

LESSON XV.

MEASUREMENT, ETC.

1. ON THE MEASUREMENT OF HEAT.—The sense of touch is our first thermometer. If I lay hold of a hot body it produces a certain change in my hand; the intelligence of this change runs up along the sensor nerves to the brain, and the feeling experienced furnishes a rough estimate of the temperature of the body. Similarly, if I place my hand upon a lump of ice, I am conscious of cold. But these sensations or feelings cannot be expressed by *numbers*, and this numerical estimate of temperature is what we at present require. The senses, in fact, may wholly deceive us. If I come into a room, and lay my hand in succession upon the metal, wood, and cloth which it contains, I experience three different sensations. When the air of the room is hot, the cloth feels warm, the wood warmer, and the metal warmest of all. If the air of the room be cold, the series is reversed, and the metal becomes coldest of all. But all these substances, while they affect the senses thus differently, have, in reality, one and the same temperature, namely, that of the air in the room. Two persons have been known to meet on a mountain, the one ascending and the other descending; the descending traveller casts his cloak from him, complaining of its warmth, while the ascending traveller draws his cloak more closely about him, and complains of cold. The fact is, our bodies are perpetually changing within certain limits. We have winter bodies and summer bodies; and a day which we should consider warm in winter would be bitterly cold

in summer. It is manifest that no certain science could be founded on the indications of an instrument so varying as the sense of touch. What then are we to do? Heat has been called a fluid; but we cannot measure this fluid by the quart—indeed we cannot measure heat directly at all; but we can measure with great accuracy the effects which heat is capable of producing, and these effects furnish us with an estimate of its quantity.

2. Whenever we speak of "quantity" in science, a certain fixed standard is always implied. Let me briefly indicate how this standard is obtained in the case of heat. The ordinary thermometer consists of a glass tube with a fine bore, which is blown out into a bulb or a cylinder at one end. The bulb and tube are partially filled with mercury. Now, one of the commonest effects produced by heat is that the addition of it causes bodies to expand, while the abstraction of it causes them to contract. Let our glass bulb and stem be surrounded by melting ice at the level of the sea, say on the coast of England; the mercury contracts as it becomes colder, the column in the glass tube sinks, and finally, when the mercury has assumed the temperature of the melting ice, the column will become stationary. You may now sail away from England to the North Pole and make the experiment there; to the Torrid Zone and try the experiment there. You will always find that the mercury, surrounded by the *melting* ice, stands at precisely the same point all the world over. It is not that the mercurial column cannot be caused to sink lower. For if the ice be suffered to fall below the exact temperature *at which it melts*, the thermometric column sinks immediately. Its constancy when placed in the melting ice is simply due to the fact that ice melts, or that water commences to freeze, at precisely the same temperature in all parts of the world.

3. Let the point at which the mercury stands be carefully marked—it is the *freezing point* of the thermometer. Let the same instrument be immersed in boiling water at the sea level on the English coast—the mercury expands and rises in the tube, until it attains the tempe-

rature of the boiling water. Here it remains stationary. Let the point at which it stands be marked—this is the *boiling point* of the thermometer. You may now repeat the experiment as before: travel north or south as you may; so long as you keep at the level of the sea, or, more accurately, so long as the height of your barometric column remains constant, the height at which the mercury stands in the thermometer plunged in boiling water will be perfectly constant also. The distance between the freezing point and boiling point is divided into a certain number of equal parts called degrees, which are sometimes marked upon the glass tube itself, and sometimes on a scale attached to the instrument.

4. The possession of these two fixed points enables us to compare one thermometer with another. It is manifest that the length to which the thermometric column expands between the freezing and the boiling temperature must depend upon the size of the bulb and the bore of the thermometer tube. If the bulb be large and the bore fine, the length through which the column expands will be greater than if the bulb be small and the bore wide. Thus the degrees of different thermometers may have *different lengths;* but they are of equal values. If in two thermometers the distance between the boiling point and the freezing point be divided into the same number of equal parts, it is plain that the body which shows 10° or 50° of temperature with one thermometer will show 10° or 50° with the other.

5. On the thermometer of Fahrenheit, which is the one mostly used in this country, the distance between the freezing point and boiling point is divided into 180 equal parts. Fahrenheit dipped his thermometer into a mixture of snow and salt, and found that the mercury fell much below the freezing point of water. He unwisely concluded that the temperature of the snow and salt was the lowest attainable; and hence he was induced to mark that temperature 0 upon his thermometer: starting from this, he found that the freezing point of water was 32 of his degrees higher in tempera-

ture; and on his thermometer accordingly the freezing point is marked 32°. This number, added to 180°, gives 212° as the boiling point of water, according to Fahrenheit's scale.

On the thermometer of Celsius, which is that most commonly used in France, the freezing point of water is called 0, and the distance between the freezing point and boiling point is divided into 100 equal parts. It is therefore usually called the Centigrade thermometer.

The thermometer of Reaumur is very commonly used in Germany, and on it the distance between the freezing and boiling points is divided into 80 equal parts.

6. Hence we see that 180° of Fahrenheit equal 100° of Celsius, and 80° of Reaumur; or 9° of Fahrenheit equal 5° of Celsius, and 4° of Reaumur. From this proportion it is easy to convert the degrees of one scale into those of another, but this variety of division is nevertheless a perpetual source of inconvenience. When a scientific man is intent upon his work, he does not wish to have his attention distracted by having to translate the language of one thermometer into that of another. Besides, the term degree is sometimes used without mention of the scale to which it belongs, and thus uncertainty and error are introduced. But nations are inert, and alter their habits with reluctance. To cope with this inertia a corresponding energy, the energy of youth, is required. Is it too much to hope that some of my readers may at a future day lend a hand in removing the inconvenience attendant on the use of three different thermometric scales?

7. ON THE BOILING POINT OF LIQUIDS.—Let us here endeavour to comprehend clearly the circumstances under which a liquid boils. Look, for example, at a vessel of boiling water: the water by heat is converted into steam, which rises in bubbles to the surface; and sometimes, where the action is not too violent, you may see one or more of these bubbles floating on the surface for a considerable time. Just consider the state of the film of water which constitutes such a bubble. It has

steam within it and air without it. Supposing the bubble to possess a surface of one square inch, we know, from a preceding article, that the atmosphere presses upon its surface with a force of 15 lbs. How is it then that the fragile thing is not crushed by this immense pressure? simply because the pressure of the steam within is exactly equal to that of the air without. The film is in fact enclosed between two elastic cushions which press upon it equally in opposite directions; and this explains an expression that you will often meet with, namely, that the pressure of steam at 212° Fahr. is equal to that of one atmosphere. But you may retort by saying that if the bubble thus depends upon the pressure of the atmosphere upon it, the boiling point of a liquid must vary as the atmospheric pressure varies. Take for example the case of a bubble floating on a vessel of boiling water at the summit of Mont Blanc; the pressure of the steam within such a bubble is also equal to the pressure of the air without it. But the pressure of the air must be far less than at the level of the sea, as we have here a great part of the atmosphere below us, and hence the steam within the bubble cannot have the same elastic force as when the water is boiled at the sea level. This reasoning would be in exact accordance with facts. The steam above *has* less elastic force than the steam below, and to produce this feebly-elastic steam less heat is required; or, in other words, the boiling point on the mountain is lower than at the level of the sea. On Donkia mountain in the Himalaya, at an elevation of 18,000 feet above the sea, water boils at a temperature of 180° Fahr. At the Hospice of St. Gothard, which is nearly 7,000 feet above the sea, the boiling point is 199°. At Berlin, which is very low, being only 131 feet above the sea, the boiling point is 211·6° or nearly 212°. I have said in another place that the heights of mountains are ascertained by means of the barometer. Precisely the same information may be obtained by means of a thermometer, on account of the gradual lowering of the boiling point as we ascend above the level of the sea.

8. People who take chocolate for breakfast can tell when the servant has omitted to make the water boil; for if the water be not boiling, or nearly so, the chocolate will not swell. Were such people transported to Donkia mountain they must be content with an inferior beverage, for there the heat of boiling water would be insufficient to make good chocolate. Tea, soup, starch, all of which require a temperature near 212°, must be very inferior when made at such a height.

9. But it is not necessary to ascend a mountain in order to see the dependence of the boiling point upon atmospheric pressure. If a vessel of hot water be placed under the receiver of an air-pump, on exhausting the receiver, and thus removing the pressure from the surface, the water will boil. In the case of the more volatile liquids, it is not necessary to heat them at all. For example, alcohol at an ordinary temperature will boil violently when the atmospheric pressure is removed by the air-pump. Let the neck of a flask half filled with water be furnished with a stop-cock, and let the water in the flask be boiled over a lamp. The cock being open, the steam generated will escape and carry with it the air which occupied the upper portion of the flask. When all the air has been removed, and the space is filled with pure steam, let the stop-cock be closed and the flask removed from the lamp. Ebullition ceases. But if a little cold water be poured upon the upper part of the flask, the cooled glass partially condenses the steam within, relieves the water of its pressure, and the liquid again boils. The whole flask may be plunged into a vessel of cold water, and a violent ebullition is thus produced.

10. I think you are now prepared to accompany me in the examination of a wonderful phenomenon, which illustrates in a striking manner the principle which we have been considering. I allude to the Geysers of Iceland. Let us approach the subject calmly, make our-

selves clearly acquainted with the facts, and proceed like philosophers to the explanation. The Great Geyser of Iceland consists of a tube 70 feet in depth and 10 feet in width, which expands at the top into a basin between 50 and 60 feet in diameter. The tube and basin are lined with a smooth plaster deposited by the water, and which is so hard that it resists the blows of a hammer. On arriving at the Geyser we will suppose a traveller to find the tube and basin full of hot water. Explosions which shake the ground are heard at intervals beneath the earth, and after these explosions the water in the basin is agitated. The Geyser column is lifted up, producing an eminence in the centre of the basin and causing it to overflow. These liftings of the column may be regarded as so many unsuccessful attempts at an eruption. In time, however, the water in the tube becomes hotter, the explosions and the agitation of the water in the basin become more frequent, the eminence in the centre of the basin rises higher than before, and finally the hot liquid wrapped in clouds of steam, is projected upwards to a height which sometimes exceeds 150 feet.

11. Sir George Mackenzie, who travelled in Iceland, and has written a description of the island, attempted to explain this phenomenon, and his theory met with general acceptance for many years. He assumed the existence of a subterranean cavern half filled with hot water, and communicating by a bent canal with the tube of the Geyser. The upper portion of this cavern he imagined to be filled with steam, and at certain intervals he supposed the water in the cavern to be suddenly heated, and steam of great force to be generated, which, reacting upon the surface of the water in the cavern, pressed it downwards and the Geyser column upwards. I mention the theory thus on account of the hold which it long retained upon men's minds. I will not dwell upon it further, but will proceed at once to the true explanation given by Professor Bunsen of Heidelberg, who visited Iceland in the year 1846.

12. In natural philosophy we must be able to guess and speculate, but the true philosopher will check his speculations whenever it is possible by an appeal to facts. Bunsen did so in his examination of the Geyser. By the immersion of suitable thermometers he made himself accurately acquainted with the temperature of the water in the tube, and found that the heat increased gradually from the top to the bottom. He ascertained the temperature at 23 hours 13 minutes, at 5 hours 31 minutes, and at 10 minutes, before a great eruption. He found that as the time of an eruption drew near, the water in the tube became hotter; but what is most remarkable, he also found that even immediately before the eruption took place. at no portion of the tube had the water attained its boiling point, that is to say, the boiling point corresponding to the pressure upon it. I hope you will understand me here. The water in the basin had merely the pressure of the air upon it, and its temperature was considerably under 212°. The water at the bottom of the tube was, it is true, considerably above 212°, but as it had here to bear the pressure, not only of the atmosphere, but also that of a column of water 70 feet high, its temperature was actually several degrees lower than that at which the liquid could boil under such a pressure.

13. But if the entire column of water be at a temperature below its boiling point, how is the ebullition in the basin to be accounted for? How are those liftings of the column, which I have called unsuccessful attempts at an eruption, to be explained? The Geyser-tube is fed by ducts which ramify through the hot rocks, and it is the steam suddenly generated in these ducts. and rushing into the tube at intervals, which lifts the column and produces the explosions. I have now to draw your attention to another very remarkable fact, and I hope if my facts come too thick that you will pause and reflect, and thus give yourself time to comprehend them clearly. Bunsen found that at a height of 30 feet from the bottom, the water approached nearer to its

boiling point than at any other portion of the tube. The actual temperature here was 252°, which was within 3° of the temperature at which the water would boil. This near approach to the boiling point can only be referred to the heat communicated to the column of water at this place by the sides of the tube.

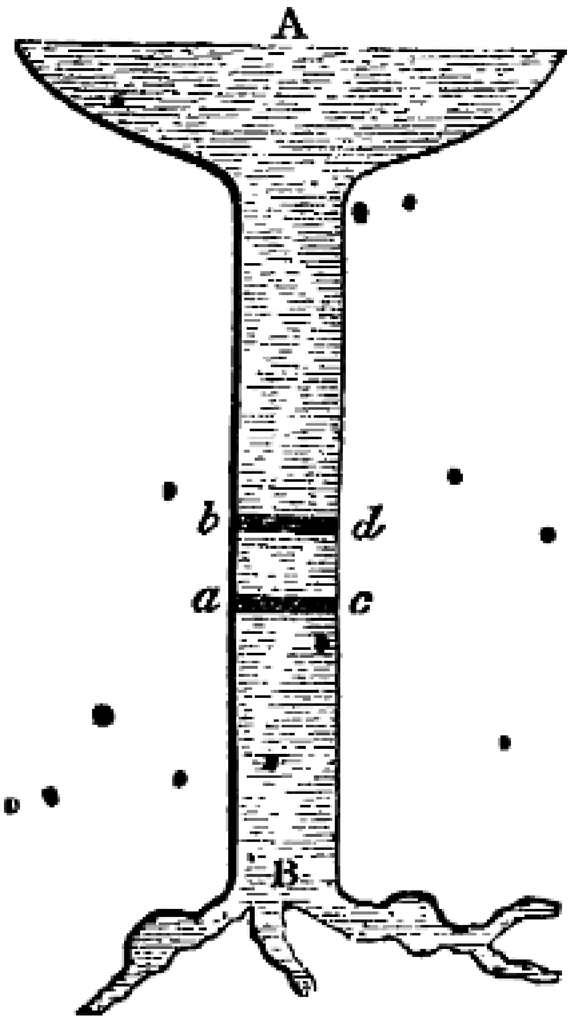


Fig. 1.

14. Thus furnished with the facts, let us now try to explain how, under such circumstances, an eruption is possible. Let A B fig. 1, be the Geyser-tube and basin, and *a c* a stratum of the liquid at 30 feet from the bottom. The temperature of *a c* just before an eruption is 252°. Suppose that by the entrance of a quantity of steam from the ducts which feed the tube, the column is lifted so as to bring *a c* up to *b d*, 6 feet higher than its former level. This supposition, be it remembered, is quite in accordance with fact, for the eminences in the basin already referred to, show that the column is sometimes lifted more than 6 feet. When *a c* is lifted to *b d*, the stratum at *b d* has 6 feet less pressure upon it than before. Under this diminished pressure its temperature is *above its boiling point.* It possesses 252° but it would boil in its new position at 250°. What is the consequence? The excess of heat is instantly applied to the generation of more steam; the column is lifted higher, and the water below *b d* is relieved of its pressure; more steam is thus generated, which in its turn diminishes the pressure. Thus relieved, the mass of water in the lower portion of the

tube bursts into ebullition, propels the liquid above it into the atmosphere; and the Geyser eruption takes place in all its grandeur.

15. The more you ponder upon this explanation, the more, I think, you will be satisfied with its beauty and sufficiency. But when a test of a theory can be applied, let us not neglect to apply it. It will be observed that the great difference between the theory of Bunsen and that of Mackenzie is, that Bunsen rejects the cavern, and finds in the tube itself a sufficient cause for the phenomenon: can we not test this by experiment? We can. I possess a tube of galvanised iron 6 feet long, and about 6 inches in diameter at its bottom. To increase the effect, and lessen the quantity of water, the tube tapers gradually towards the top; here it enters water-tight through the bottom of a basin of sheet zinc about 5 feet in diameter. The tube is filled with water; a fire is lighted beneath it, and at about 2 feet above the bottom, the tube is embraced by a second small fire, to imitate the lateral heating of the pipe of the Geyser. With this simple apparatus all the phenomena of the famous Iceland spring can be imitated to perfection. One experiment often made with this apparatus is very striking, and further illustrates the principle at present under consideration. The top of the tube is stopped with a cork; the water thus confined does not boil at 212°, but goes on heating until its vapour is sufficiently strong to force out the cork. Its excess of heat is then instantly applied to the generation of steam, and the consequence is, that the water is projected upwards to a height of 30 feet. This is an exact imitation of the action of a second spring in Iceland, which is called the Strokkur. The natives throw clods into its tube and choke it up; after a little time these are ejected like the cork, and the water of the spring is projected to a height surpassing even that attained by the Great Geyser.

LESSON XVI.

LATENT AND SPECIFIC HEAT.

1. On latent heat.—Many of the terms of science are indicative of the theoretic views of those who first used them. Thus the man who first employed the term at the head of this section imagined heat to be something which could hide itself, in some way or another, in the pores of matter, so as to elude ordinary methods of observation. Latent heat always comes into play when a body changes its state of aggregation; when it passes from the solid to the liquid, or from the liquid to the vaporous or gaseous condition. While the case of water is still fresh in our minds, let us take it for an example. Suppose a lamp which burns with a perfectly constant flame, and which always gives out the same quantity of heat per minute, to be placed under a vessel containing water at 32° Fahr., that is, just at the freezing point, and a thermometer to be placed in the water; as heat is communicated to the latter, the mercury will rise, until the point 212° is attained. Here the water will commence to boil, *and here the thermometer will cease to rise.* You may continue to apply heat, the lamp may be just as active as before, and communicate its due amount of heat per minute to the vessel, yet higher than 212° the water will not rise! If you immerse your thermometer in the steam which issues from the vessel, it also will show a temperature of 212°, and no higher; so that though the heat is given, it does not show itself anywhere; it has hidden itself in the steam, or, to use the language of the discoverer of the fact, it has become *latent.* Let us now seek to be accurate in our observations, and endeavour to find the quantity of heat which is disposed of in this way. Let us suppose the experiment again commenced, and the time required by the lamp to heat a single ounce of water from 32° to 212°, or through 180°, to be accurately noted. Let the action now be continued until all the water has

been reduced to a state of vapour; it will be found that the time necessary to produce complete evaporation is almost exactly 5½ times the time required to raise the water through 180°. Hence, if the water had not boiled, but had gone on heating after it had reached 212° as before, it would, in the time necessary to reduce it all to vapour, have augmented its temperature by 5½ times 180°, or 990°. These 990° have been rendered latent by the steam, and this number is called the *latent heat of steam.* Added to the 212° which the water already possessed, it would give 1202° for the total temperature of such water; but instead of reaching this, it is cut short at 212°, and all beyond this point is hidden in the vapour.

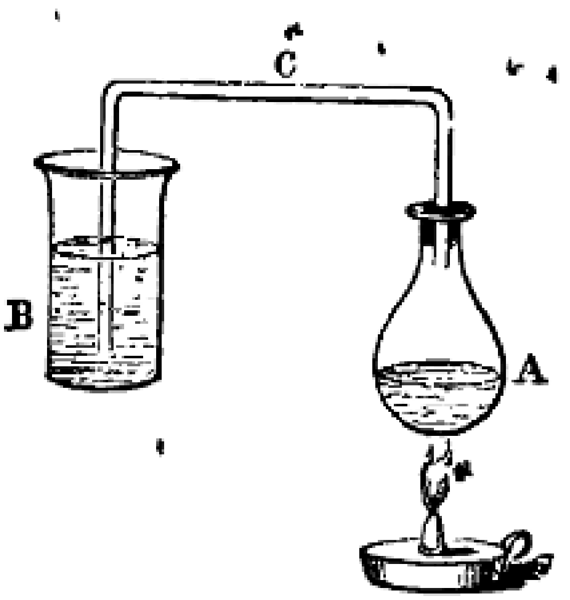


Fig. 2.

2. Let us now reverse the experiment and see whether we cannot bring this heat from its hiding place. Let A, fig. 2, be a flask containing water, and through its cork let one end of a glass tube C pass air-tight. Let the other end of the tube dip into water at 32° contained in the vessel B. Heat being applied to the flask A until the water boils, the steam will issue through C, and be condensed by the water in B. By degrees, the water in B becomes heated, and it finally boils. We will now endeavour from this experiment to determine the latent heat of the steam, and thus check the result which we have already obtained. Suppose the vessel B at the commencement of the experiment to have contained 5½ ounces of water, it will be found at the moment when it commences to boil to contain 6½ ounces; that is to say, 1 ounce of water in the shape of steam has gone over from A; that steam had a

temperature of 212°, the water which it boils has a temperature of 212°, consequently the ounce of steam has boiled the 5½ ounces of water *without losing any sensible temperature of its own.* It has boiled the water by its latent heat.

3. Now, suppose that a man with 100 shillings in his purse distributes these equally among five persons, each person would receive 20 shillings; if instead of thus dividing his money he gave it all to a single individual, this person would, of course, possess five times as much as any one of the five would have done. So also if the ounce of steam, instead of distributing its heat among 5½ ounces of water, had given it all to one ounce, that ounce would have received 5½ times the number of degrees of the larger mass; and as the number of degrees received by the larger mass is 180°, a single ounce would receive 5½ times 180°, or 990°. Thus, in our first experiment we found that one ounce of water on being reduced to steam, hid 990° of heat; and in our second experiment, we have brought this heat from its hiding-place, and found that it would be exactly capable of heating an ounce of water (supposing it not to boil), 990°. One result, therefore, confirms the other. I may remark, however, that recent experiments make the latent heat of steam 967° instead of 990°.

4. The enormous absorption of heat which accompanies the conversion of a liquid into vapour explains many singular phenomena. If you place a drop of ether upon the back of your hand, the liquid, being very volatile, speedily evaporates: heat is absorbed from the hand, and a sensation of cold is produced. The wine-coolers of the East consist of vessels of porous earthenware. A bottle of wine is placed within the cooler, and the space between the two is filled with water. This oozes through the porous cooler, and moistens the outside of it. The moisture is evaporated, and its place continually supplied with water from behind. Through this continued production of vapour a great amount of heat is abstracted from the water; the latter becomes cooled, and

produces the desired effect upon the wine. If the porous vessel be placed in a current of air, evaporation is hastened, and the cooling is more speedily effected.

5. Again; a stone in Lapland, and a stone on the burning plains of Sahara, have very different temperatures; but a traveller in Lapland has almost exactly the same temperature as a traveller in Sahara. The health of the human body appears to require that its temperature should only vary within very narrow limits, no matter where upon the earth's surface it may be placed. How does nature secure this constancy amid such varied external conditions? The evaporation from the body is the regulator. In hot countries this is greater than in cold, and thus the excess of heat is carried away.

6. Let a watch-glass containing ether be placed upon a small dish with a little water between the glass and dish, and let the whole be placed under the receiver of an air-pump: by working the pump evaporation is promoted, and in this way cold may be produced sufficient to freeze the watch-glass to the dish on which it rests. The experiment is most easily made with two watch-glasses which have their bottoms roughened by grinding. Turn one upside down, place a drop of water upon it, and on this place the second glass containing the ether. A very few strokes of the pump will be sufficient to freeze the glasses together. Care must be taken not to allow any portion of the ether to mix with the drop of water to be frozen, as this, on account of the difficulty of freezing the ether, would completely vitiate the experiment.

7. The cold produced by evaporation is strikingly exhibited by the instrument called the cryophorus. This instrument consists of two bulbs, A and B (fig. 3) united by a glass tube. A portion of water is introduced through an aperture at C, and is boiled until all the air is expelled through C, when the aperture is sealed with a blowpipe. The instrument is now complete. To show its action, let all the water be brought into one of the bulbs, say A, and let the empty bulb B be surrounded by a

freezing mixture. The water in A evaporates and makes its way to B, where it is condensed, thus leaving room for the formation of more vapour. Heat is thus continually abstracted from the water in A, which, after a short time, is converted into a mass of solid ice.

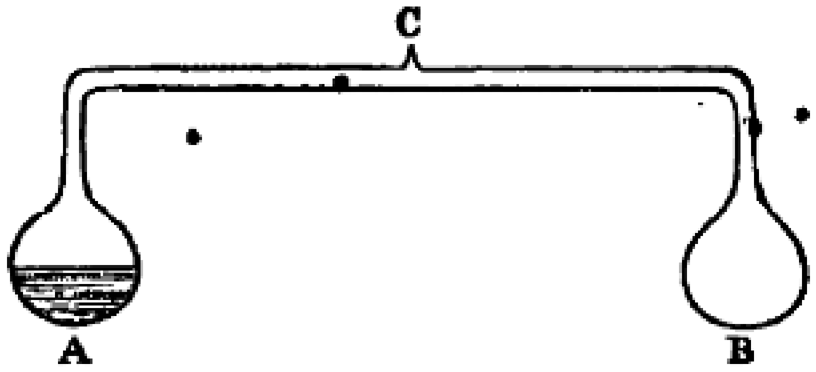


Fig. 3.

8. But perhaps the most remarkable case of refrigeration is that furnished by carbonic acid. At ordinary temperatures this substance is a gas: it is exhaled from the lungs, it effervesces from champagne and soda-water, and if an acid be poured upon chalk or marble, the gas is liberated in great abundance. By mechanical pressure this gas can be made to assume the liquid condition, and in this state it is preserved in iron bottles of great strength. When the cock of a bottle, filled with this liquid, is turned so as to open a communication with the air, a portion of the substance flashes suddenly into vapour, but not all. So great is the cold produced by the vaporization that a portion is actually frozen, and the solid carbonic acid may be collected as a pure white snow.

9. It is now necessary to say a word regarding the heat absorbed when a body passes from the solid to the liquid condition. Let us take ice as an example. Supposing we take the substance in midwinter, at a temperature lower than the freezing point—say at 15° Fahr., and place it in a vessel with a constant flame underneath it. A thermometer placed in the vessel will first show an increase of temperature; the mercury will rise

until it reaches 32° ; at this point the ice will commence to melt, and at this point also the upward motion of the mercury will be arrested. As long as the ice continues melting, the thermometer will show a constant temperature of 32°, and when the ice has disappeared, but not before, the mercury will resume its upward motion.

It is manifest that we have here an instance similar to that already described in the case of steam. During the melting of the ice, heat is continually communicated by the lamp, but it does not show itself upon the thermometer. It seems to be hidden in the water; to use the ordinary term, it is rendered latent.

10. How are we to estimate the quantity of heat thus absorbed? We may do it in this way :—Take a pound of ice at 32°, that is, just at its freezing point. Take a pound of water at a temperature of 175°. Mix these together; when the experiment is properly made, it is found that a pound of water at this temperature is just sufficient, and no more, to melt the pound of ice. When the melting is complete, the resulting liquid is at a temperature of 32°; consequently the ice, on being rendered liquid, has received 175° – 32° = 143° of heat, without becoming sensibly warmer. To the thermometer and to the hand it is of the same temperature before it is melted and after it is melted. The 143° of heat communicated to it have therefore been rendered latent. This number expresses the latent heat of water.

11. We may check this result by the following experiment:—Let two lamps which give out the same quantity of heat per minute be placed under two equal vessels, one of which contains a pound of ice at 32°, and the other a pound of water at the same temperature. Let a thermometer be placed in each vessel. That immersed in the water will rise from the commencement of the experiment; that immersed in the ice will remain stationary at 32° until all the ice has been melted. At the moment when the last bit of ice disappears let the thermometer, plunged in the water, be read off: it will

show 175°. Subtracting 32° from this, we have 143° as the quantity communicated to the water by the lamp; but the same quantity of heat has been communicated by the second lamp to its vessel without raising its temperature at all. It has been applied to liquefy the ice; hence, as before, we arrive at the conclusion that these 143° have been rendered latent during the liquefaction.

12. It is not difficult to show that water in freezing yields up the heat thus rendered latent; but the experiment is much more striking with sulphate of soda. Let as much of this salt as possible be dissolved in boiling water, and let the solution be placed in a flask or beaker to cool: if it be permitted to remain perfectly quiet, it will cool gradually, and remain, when cold, in a liquid condition. If a thermometer be now plunged into the solution, it immediately thickens to a solid round the thermometer, and the process of crystallization thus commenced speedily extends itself throughout the entire mass. At the same time the thermometer will be seen to rise, the latent heat of the liquid being rendered free by the passage of the substance to the solid state.

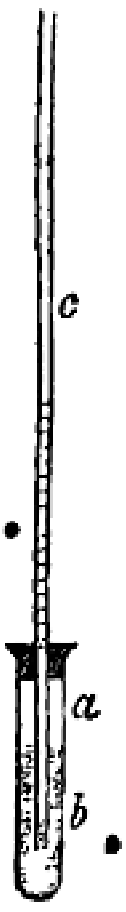


Fig. 4.

13. The dissolving of a little saltpetre in water instantly reduces its temperature, as may be seen by the falling of a thermometer plunged in the liquid. Air-thermometers, being more sensitive than mercurial ones, are the best for such experiments. Any boy may readily make an air-thermometer for himself. Let a common test-tube be taken and furnished with a well-fitting cork. Through this cork let a small glass tube pass air-tight, and let its lower end dip into a little coloured water (*b*, fig. 4) at the bottom of the test-tube. When the latter is immersed in a warm liquid, the air at *a* expands, presses upon the surface of the water, and forces it up

in the tube, *c*. Very small differences of temperature may be thus rendered manifest.

14. If space permitted I might show you the influence of the facts we have been considering upon the climates of various countries. Europe has a remarkably mild climate, considering its position upon the surface of the globe. The eastern coast of America has a climate far more severe than the opposite one of western Europe. The river Hudson, which is in nearly the latitude of Rome, is sometimes frozen during three months of the year. Nay, so great is the cold observed in some parts of North America, that it gave rise to the idea that the north pole of the earth was once in this region, and that through some great convulsion of Nature the axis of the earth had been shifted from the position which it once held. But this idea would scarcely have arisen had it been known how immovable the position of the earth's axis really is; and, besides this, our present progress in meteorology has quite explained the difficulties to which we refer. Compare the *western* coast of America with the western coast of Europe, and the differences of temperature disappear. The land between the Rocky Mountains and the Pacific Ocean has a European climate; the reason being that the vapours drifted towards the continent from the Pacific are condensed by the mountains; in condensing, they yield up their latent heat, and thus preserve the climate mild. It has been thought that the warmth of Europe was due to the descent of air which had passed over the hot soil of Africa; but this air, on account of the velocity imparted to it from west to east by the diurnal motion of the earth, does not reach Europe at all. The cradle of our southerly winds is the West Indies, and the secret of the mildness of Europe is, that it is the condenser of the vapour of the Caribbean Sea.

15. On specific heat.—In treating of latent heat I said that the term was suggestive of the theoretic opinions of the person who first used it. Heat, like

light, magnetism, and electricity, was ranked among what were called imponderable bodies—bodies without weight, but still capable of being mixed up with ordinary matter. Heat, looked at from this point of view, was called by the Germans "wärmestoff"—that is, the stuff or material of heat; and in chemical books we still find the combination of bodies with heat spoken of, just as such books speak of the combination of one material substance with another. This is called the material theory of heat. Now it is found that different bodies require very different amounts of heat to make them equally warm. Suppose, for example, all the heat given out by the combustion of an inch of candle to be communicated to a pound of water at a temperature of 32°; the water will have its temperature augmented a certain number of degrees. If the same amount of heat be imparted to a pound of mercury, the temperature of that liquid would be raised thereby far higher than that of the water. In fact, to raise a pound of water a certain number of degrees in temperature would require thirty times the heat necessary to raise a pound of mercury the same number of degrees. Hence, in accordance with the material theory of heat, it was supposed that water possessed a greater power than mercury of drinking in the heat. This power was called its *capacity for heat*, and sometimes its *specific heat*. We have referred to two liquid bodies; but solids also differ from each other in this respect. If the same absolute amount of heat be communicated to a pound of lead and a pound of iron, when examined by the thermometer the iron will be found to be much cooler than the lead; it would require a greater amount of heat to raise it to the same temperature. Hence iron is said to have a greater capacity for heat, or a greater specific heat, than lead has. If we immerse a pound of lead and a pound of iron in boiling water, the quantity of heat taken in by the iron in order to bring it up to the temperature of the boiling water will be greater than that taken in by the lead. How can we prove this? Simply by plunging our lead and iron into two separate vessels containing the same amount of cold water. The water in contact with the iron will be much more heated than that in contact with the lead. Or if a ball of iron and a ball of lead, heated in the manner described, be placed upon a thin plate of stearine, the iron will melt its way through and fall to the ground while the lead remains sticking in the mass. Such experiments as these inform us in a general way that one substance has a higher specific heat than another; but they do not tell us how much the specific heat of one body exceeds that of another. To ascertain this, more accurate experiments must be resorted to. Perhaps the most celebrated experiments on this subject are those of Lavoisier and Laplace—the former a great chemist who suffered death by the guillotine during the first French Revolution; the second, a celebrated mathematician. In their experiments they made use of an instrument called a calorimeter, of which the following is a description :—

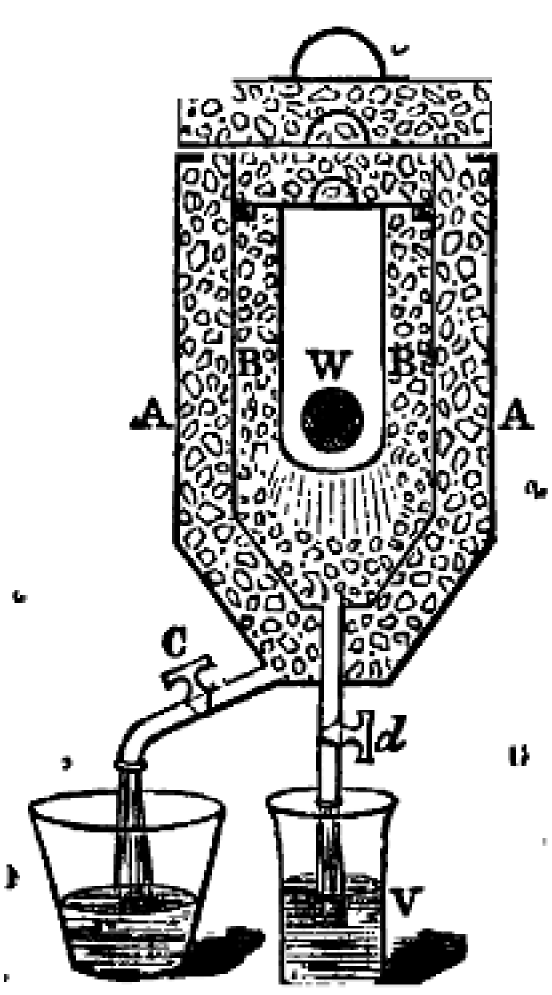


Fig. 5.

16. A (fig. 5) is a vessel of sheet metal; B is a second vessel of a similar shape, placed within the first. A cover being placed upon each of the vessels, A and B, there is a space between the two vessels all round. This space is filled with pounded ice, which, when the vessel is placed in an atmosphere above 32°, gradually melts, and the melted water is carried off by the cock C. Within B is a third vessel, and the space between it and B is also filled with pounded ice. Each vessel is furnished

with a cover, so that the ice can be placed all round, as shown in the figure. Within this third vessel, the warm body, W, whose specific heat is to be determined, is placed. Now let us understand the instrument: the outer jacket of pounded ice effectually protects the ice in the vessel B from the action of the atmosphere. The ice in B is thus preserved at 32°, and cannot be melted by the external air. Hence, whatever is melted in B must be wholly due to the heat yielded by the body, W. The liquid thus produced is carried off by the cock *d*, and received into the vessel, V.

17. The principle from which Lavoisier and Laplace started was, that the quantity of heat which a body contains will be measured by the quantity of ice which it is able to liquefy. If we place one pound of iron, heated up to the temperature of boiling water, in the apparatus, and permit it to cool down to 32°, and then subject our pound of lead to the same experiment, on weighing the amount of water produced by each, we should find them to be in the ratio of 11 to 3, that is to say, a pound of iron in falling through the same number of degrees yields nearly four times the quantity of heat yielded by an equal weight of lead.

18. The specific heat of a body accurately defined is the quantity of heat which the body requires to raise the unit of weight, say a pound of water, 1° in temperature. But the quantity of heat required to raise the temperature of a body 1° is the quantity which it loses in falling through 1°; and this latter is measured by the quantity of ice which it is able to liquefy.

Supposing a body at 42° to be placed in the calorimeter and permitted to sink to 32°, or through 10°; if the quantity of ice melted by the body be 10 grains, this would be a grain for every degree; or, more generally, if we divide the weight of melted ice by the number of degrees through which the body melting it has fallen, we obtain the quantity which the body would melt by falling through 1°. This quantity expresses the specific heat of the body.

19. In tables of specific heat the standard referred to is that of distilled water: its specific heat is set down as 1. The following table shows the specific heats of a few other well-known substances:—

Iron	0·11379
Zinc	0·09555
Copper	0·09515
Silver	0·05701
Lead	0·03140
Bismuth	0·03084
Platinum	0·03243
Gold	0·03244
Mercury	0·03322

We here see how greatly the specific heat of water predominates over those of all the other substances mentioned. The specific heat of water is nearly 10 times that of iron, 18 times that of silver, and is more than 30 times that of mercury. This is the place to remark how suitable its low specific heat renders mercury for thermometric purposes: it is promptly affected by changes of temperature, which it would not be if its specific heat were high.

Calling the specific heat of water 1, that of atmopheric air is 0·25, or just one-fourth part that of water. Hence a pound of water in losing 1° of heat would heat a pound of air 4°, or it would heat 4 pounds of air 1°.

But a pound of air fills about 770 times the space of a pound of water, and hence 4 pounds of air fill 3080 times the space of a pound of water. Therefore a pound of water by parting with 1° of temperature would be able to raise 3080 times its own bulk of air 1°.

20. The vast importance of this property of water as a regulator of climate at once suggests itself. No wonder that the climates of islands are so much milder and more equable than those of continents. The surrounding sea, thirsty, as it were, for the sunbeams, drinks them in, but nevertheless preserves itself comparatively cool, and thus tempers the island air. In winter the heat thus stored up is slowly given out; every gallon of water on giving up its degree of heat, warming 3080 gallons of air by the same amount, and thus shielding the island from winter cold. We here see the explanation of the fact that the winter of Iceland is less severe than that of Milan. We can also explain why it is that with us laurels and other plants thrive in the open air, which are killed by the winters of more southern lands; while our summers refuse to ripen the grapes which those lands produce in abundance. Thus it is that the simplest facts which we learn in the laboratory constitute the stepping-stones by which the human mind attains to the accurate comprehension of the grandest pheonomena of Nature.

LESSON XVII.

EXPANSION BY HEAT.

1. **On the expansion of solids by heat.**—I have already stated that the expansion of mercury by heat is made use of as a measure of the heat which produces the expansion. All bodies, without exception, are affected in this way by heat, but all are not affected in the same degree. A rod of steel, for example, on being heated from 32° to 212°, expands $\frac{1}{927}$th of its own length; whereas a rod of lead similarly heated expands $\frac{1}{350}$th of its length: the expansion of lead by heat is, therefore, much greater than that of steel. Brass expands $\frac{1}{335}$th of its length on being heated from 32° to 212°, whereas iron expands only $\frac{1}{817}$th. Now suppose a bar of brass and a bar of iron to be closely riveted together, so as to form a single compound bar, as shown in

Fig. 6.

fig. 6. When such a bar is heated, what must be the consequence? The brass B expands more than the iron I, and in order to give this difference of expansion room, the compound bar is bent into a curve, as in fig. 7, the brass bar forming the outside of the curve. If instead of heating the straight compound bar we cool it, the brass contracts most, and the bar is bent in the opposite direction. For certain chemical experiments it is necessary to have a metallic wire fused into glass tubes; both glass and wire must of course be red hot when this fusing takes place; and if, in cooling, one of them contracted more than the other, the rupture of the junction between them would be inevitable. Now barometer glass expands, on being heated, from 32° to 212°, $\frac{1}{1173}$th of its own length. Were we to fuse a bit of gold wire into such glass, rupture would assuredly take place in cooling, for gold expands on being heated from the freezing to the boiling point of water $\frac{1}{695}$th of its length. Fortunately, however, there is a metal, *platinum*, whose expansion is $\frac{1}{1167}$th of its length, or almost exactly equal to that of glass. This metal is therefore always used in the construction of the instruments to which I have referred.

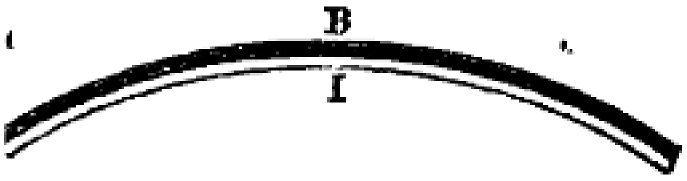


Fig. 7.

2. In the construction of bridges and buildings where metal tubes or beams are introduced, and also in the laying down of railroads, care must always be taken to allow for the expansion due to variations of temperature, for the force with which a body expands under the influence of heat is almost irresistible, and might produce serious consequences if it were not permitted free play. There is on the line of rails between London and Manchester a greater length of iron by about 500 feet in summer than in winter; and to permit this ex-

pansion to take place, the rails, when they are laid, are not brought close up end to end. Iron cramps in masonry often work themselves loose on account of the inequality of the expansion between them and the stone. The tires of wheels are heated before they are put on; in cooling they contract, and draw the woodwork together with great force. Hot rivets act similarly. The force of contraction has also been made use of to set the walls of buildings erect. If I remember aright, the experiment was tried with the cathedral of Armagh. The walls of the building gradually leaned away from each other, and to draw them together bars of iron were placed across the cathedral, passed through the walls, and furnished with nuts at the ends which might be screwed tight to the walls. The bars were heated and expanded. The nuts at the ends were made tight, and then the metal was suffered to cool; during its contraction it drew the walls together with an irresistible pull; and by repeating the process the walls were finally set erect.

3. In connexion with this subject a very interesting fact has been recently observed. A sheet of lead which lay on the south side of the choir of Bristol cathedral was observed to have slipped bodily down the roof, through a space of 18 inches, in two years. You might imagine that this was simply due to the slope of the roof, but the slope was such that the lead would never have slid down it by its own weight. How then did the lead get down? The case is instructive, and I would therefore draw your attention to it.

4. Imagine such a sheet of lead, lying upon an inclined roof, exposed to the temperature of a sunny day. It expands. If it lay upon a horizontal surface it would be pushed out in all directions equally by the expansion, but as it lies upon a slope, it will slide with greater facility downwards than upwards. The upward movement is opposed by gravity, while the movement downward is assisted by gravity. If the position of the upper and lower edges were marked by chalk before

the expansion took place, the lower edge, for the reason just given, will extend further over its chalk mark than the upper. Now suppose the chill of night to act upon the lead; it will contract. But it is easier to pull the upper edge down than to pull the lower edge up. If the position of the upper and lower edges were marked with chalk, as in the former case, before the contraction, it would be found that after the contraction the upper edge had moved further from its mark than the lower one. By expansion, therefore, the lower edge is pushed downwards, and by contraction the upper edge is pulled after it. Thus the mass of lead creeps like a worm, and although the space passed over in a day would be nearly imperceptible, the progress is sure, and in two years amounted, as I have said, to 18 inches.

Fig. 8.

5. The time which a pendulum requires to accomplish an oscillation depends upon its length: a long pendulum oscillates more slowly than a short one. Hence a pendulum, acted upon by variable weather, vibrates sometimes quicker, sometimes slower, and consequently would give inaccurate results. Various means have been used to render the oscillation uniform. You will sometimes see a vessel of mercury suspended at the end of a pendulum. When the temperature of the day increases, both the pendulum rod and the mercury expand, but the former expands *downwards*, while the latter expands *upwards*, and by this opposition the centre of oscillation, as it is called, is preserved constant. The gridiron pendulum is also very common; its principle will be understood from fig. 8. S is the knife edge on which the pendulum is suspended. A B C D

is a rectangle composed of iron rods: through a hole in the cross piece C D the rod $p\ q$ passes. E G is a cross piece capable of moving up and down; and attached to this cross piece are the two brass rods E F and G H, which also rest upon the cross piece C D. When the warmth of the day increases, the rods A C and B D expand, and also the central rod $p\ q$. All these tend to push the pendulum bob q farther from the point of suspension. But the brass rods E F and G H also expand, and their action is to lift the pendulum bob and cause it to approach nearer the point of suspension. In the construction of the pendulum it is so arranged that these opposing actions exactly balance each other, so that the pendulum is maintained at a constant length. In fact we know from experiment that the expansion of brass is to that of iron as 1½ is to 1; hence if the length of iron to that of brass in the pendulum be in the same ratio, the expansions neutralize each other, and a perfect "compensating pendulum" is obtained.

6. It has already been shown that different solid bodies expand differently when heated; but in some cases the same solid body expands differently in different directions. It is easy to conceive that in crystalline bodies the atoms may be packed more closely together in some directions than in others, and hence we might expect that, when such a body expands under the influence of heat, the atoms would be pushed asunder with different forces in different directions. Experiment justifies this conjecture. When the crystal gypsum is heated, it changes its shape, which would not be the case if it expanded equally in all directions. The crystal Iceland spar, when heated, expands considerably in the direction of its axis, but, strange to say, in a direction at right angles to the axis it *contracts.* This contraction, however, is not sufficient to balance the expansion; and the final result is that the volume of the crystal is augmented. It is easy to conceive that when a crystalline body of which the component crystals are confusedly arranged is heated, the unequal expansion of its various

parts may produce rupture among them to a greater or less extent, and this is doubtless the cause of the snapping noise sometimes heard during the cooling of melted zinc or antimony, and sometimes even in the case of the bars of a grate.

7. On the expansion of liquids by heat.—Liquids expand more than solids under the influence of heat. Let a retort be filled with water as in fig. 9, and let the vessel be chosen with a neck so narrow that when it is filled and inclined as in the figure, the capillary attraction of the neck shall be sufficient to prevent the liquid from flowing out. A lamp being placed underneath the retort, the dropping of the water into the beaker, B, soon demonstrates the expansion of the liquid.

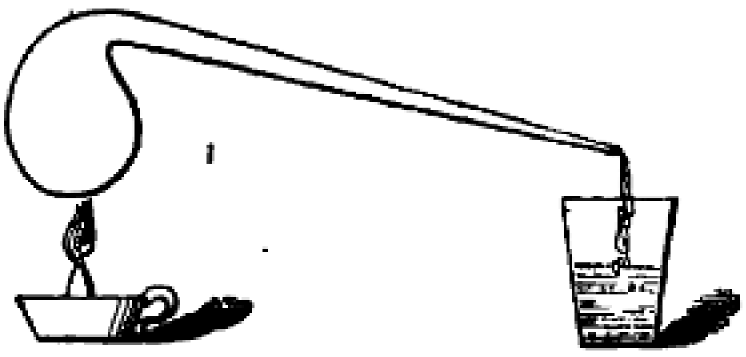


Fig 9

8. When a vessel containing water is placed upon a fire, the lower portion of the liquid expands, and becoming thereby lighter, it ascends, while the heavier liquid sinks to supply its place. This in its turn becomes heated, and rises, being replaced by cooler liquid as before; and thus the heat communicated to the bottom of the vessel is distributed through the liquid. By placing in the water cochineal, or some other opaque powder of nearly the same specific gravity as the water, the existence of these up-and-down currents may be demonstrated. Similar currents exist in the tube of the Great Geyser already described. When scraps of paper are cast into the centre of the basin, they are driven from the centre towards the edge, and thence sucked down-

wards. The tube has an ascending current along its centre, and a descending current along its sides.

9. Let us now reverse our conceptions, and consider the case of a sheet of water exposed to the chilling influence of a freezing atmosphere. The surface of the water in contact with the air is cooled; it contracts, becomes heavier, and sinks, while the lighter water from below rises to supply its place. In this way the warmth is drawn from the depths and given to the atmosphere. This process continues till the superficial layer is cooled down to 39° Fahr., and at this point the contraction of the water ceases. At 39° Fahr. water possesses the greatest density that it is capable of possessing, and as it sinks below this temperature, and approaches the freezing-point, it *expands*. Hence the water which is at the surface when the temperature 39° is attained, remains there; it does not sink, but continues to float like a layer of oil upon the heavier water. When it reaches 32° it freezes, and thus forms a solid lid of ice, which shuts down the warmer water. Beneath this lid the fish may dwell unharmed; whereas if it were otherwise, if the abstraction of heat continued until the entire mass were frozen, the fish would be crushed to death by the act of congelation. Does it not appear as if Nature, in arresting the contraction of water at 39°, had stepped aside from her wonted course in order to preserve her creatures! On this point I will not dwell, as, with our limited knowledge of the purpose which runs through Nature, we are very liable to make mistakes. The metal bismuth, on cooling from a state of fusion, behaves exactly like water, although in its case there are no fish to be protected.

10. In cooling from 39° to 32° the expansion of water is gradual; but in the act of congelation a sudden expansion takes place, and the ice which results is considerably lighter than the water from which it is produced. The force of this expansion is irresistible; it will burst the thickest bomb-shell. It is a common experiment to fill an iron bottle with water, screw it

close, and place it in a freezing mixture to congeal. The act of congelation is accompanied by the bursting of the bottle. Before filling a bottle for this experiment, it is well to boil the water and expel the air. The same experiment may be made with fused bismuth. I once filled an iron bottle with the melted metal, and closing it with a screw tap, permitted it to cool. The bottle was rent from neck to bottom by the expansion of the metal on solidifying.

11. ON THE EXPANSION OF GASES BY HEAT.—Of all bodies, gases undergo the greatest change of dimensions on the application of heat. It resulted from Dalton's experiments that 1000 cubic inches of air, on being heated from 32° to 212°, expanded to 1392 cubic inches. It was found by Gay Lussac, in 1804, that 1000 cubic inches of air, on being heated from 32° to 212°, became 1375 cubic inches. The more recent researches of Rudberg, Magnus, and Regnault, show that these numbers are above the mark. Instead of 1375 it ought to be 1367 cubic inches. Hence, on being heated 180 degrees, the volume of a mass of air becomes augmented by $\frac{367}{1000}$ths of the volume it possessed at 32°.

12. Experiments prove that the expansion of air is uniform, that it is augmented by the same quantity for every degree of temperature imparted to it, so that the expansion due to 180° is 180 times the expansion due to 1°. Hence, to find the expansion due to 1°, we have to divide the fraction $\frac{367}{1000}$ by 180: this gives us $\frac{367}{180000}$, or, reduced to its lowest terms, $\frac{1}{490}$. This result may be thus expressed in words;—When atmospheric air, at a temperature of 32°, is heated 1°, it expands $\frac{1}{490}$th of its volume. If raised 2°, the expansion would be $\frac{2}{490}$ths; if 3°, $\frac{3}{490}$ths of the volume which it possessed at 32°. What is true of atmospheric air is true of other gases. They all expand in the same proportion, except those which are near their point of condensation.

13. Supposing, then, that I asked at what temperature

a cubic foot of gas at 32° would enlarge its volume by one-half, you would of course reply, at a temperature of 245° above 32°, for here the expansion would be $\frac{245}{490}$ths, or one-half. If again I asked at what temperature a mass of gas which measures a cubic foot at 32°, would double its volume, you would reply to me, at 490° above 32°, or, in other words, at a temperature of $490+32=522°$, as shown by the thermometer.

14. It is easy to show the expansion of air by heat. Let the neck of a retort dip into a vessel of water as in fig. 10; on bringing a spirit-lamp underneath the retort, the air within it expands, and is driven in bubbles through the water. On allowing the retort to cool, the air will shrink to its former dimensions, and the consequence is, that the water, pressed upon by the atmosphere, will follow it and partially fill the vessel. In like manner, in the process of cupping, a glass, with the air within it rarified by heating, is inverted over the wound; the air cools and contracts, and the blood, and even flesh, are forced by the pressure of the atmosphere into the glass, just as the water is forced into the retort.

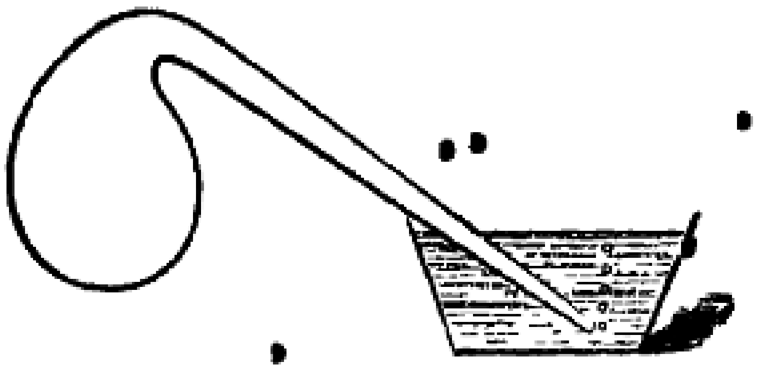


Fig. 10.

15. On its expansion by heat, air becomes lighter, and will, if it can, ascend into the atmosphere. While I write, the flame of a candle is before me; the erect position of that flame is due to the ascent of the column of heated air. I place my hand above the candle, and find it struck by this "hot blast." I pluck a hair from my head, and make it act as a weather-cock; when placed above the flame it is blown upwards. Take a

bent tube, such as that shown in fig. 11, and heat the corner at A by a spirit-lamp; the air will ascend the leg A B, and, to supply its place, a descending current will establish itself in the other leg. If a smoking taper be held at C, the smoke will be carried down, and will make its appearance at B.

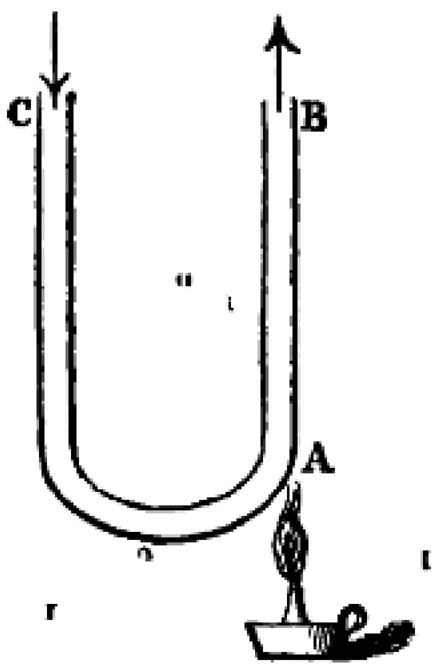


Fig. 11

16. The products of the combustion of coal-gas are very injurious to health, and it is therefore desirable to have them carried away from the room in which the gas is burned. To accomplish this, Mr. Faraday invented a lamp, the principle and construction of which there will, I think, be now no difficulty in understanding.

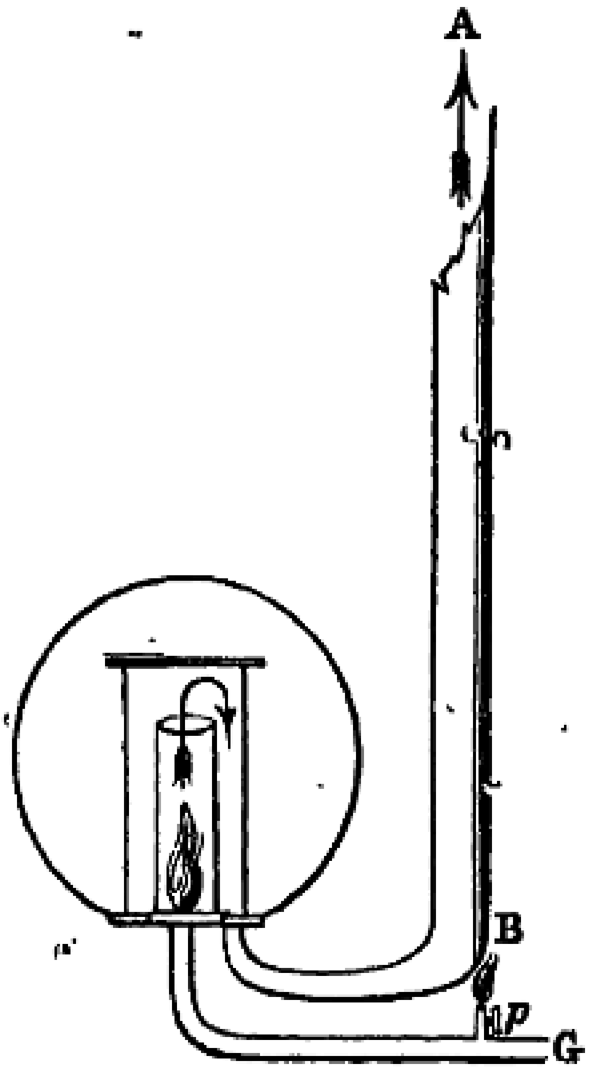


Fig. 12.

The gas enters the lamp from the pipe, G (fig. 12): immediately round the flame is a common glass chimney, and around this again a larger one, which has a plate of transparent mica placed upon the top of it. Round both chimneys is a spherical shade of diaphanous porcelain, not open at the top as ordinary shades are. A B is a tube of bronze, the end A of which communicates with the atmosphere; the other end of the tube communicates with the space between the two glass chimneys. At *p* is a small gas jet, and the first thing done is to ignite this. It heats the corner, B, of the bronze tube, and thus produces an upward current through the latter. Let the lamp be now lighted, and the chimneys and shade arranged as in the figure. The current of heated gases from the lamp ascends through the inner chimney, and to supply the place of the air displaced at B, the current turns downwards, as shown by the arrow, reaches B, and is carried off through A B into the atmosphere. Thus, you see, not a single particle of the gases generated by combustion enters the room. The noxious nature of these gases may be demonstrated by placing a candle at A. It will be immediately extinguished by the carbonic acid present there. After the lamp has been in action for a little time, the jet, *p*, may be extinguished; for the tube, A B, being once heated by the gases proceeding from the lamp, will itself keep up the necessary current.

17. The following experiment is also instructive:—Let a candle, C, be placed upon a plate, P (fig. 13), and let a glass jar with its mouth open be placed over the candle, a little water being poured upon the plate to prevent the entrance of air at the bottom of the jar. Let a glass chimney, A B, be placed upon the jar. Although in this arrangement the lighted candle communicates with the atmosphere, it will nevertheless go out; for the products of combustion, seeking to ascend, are opposed by the pressure of the external air. Let a piece of cardboard, D E, be now introduced so as to divide the tube, A B, into two halves. The products of combustion choose one-half of the tube and ascend, while the air descends through the other half to supply their place. In this way fresh air is supplied to the candle, and it

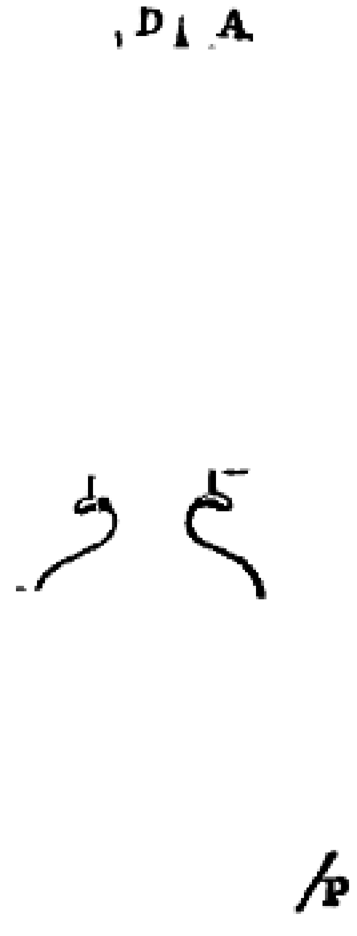


Fig. 13.

burns as long as it lasts. Of course the principle of ventilation here described applies as much to the shaft of a mine as to the tube used in our experiment.

18. It is the currents produced by heated air that ventilate our rooms. The air about the fireplace is carried up the chimney, and the entrance of air through doors and chinks makes good the loss. In this way draughts are produced, which, though they may afflict us with rheumatism, at all events clear away the carbonic acid and supply us with fresh air. In a warm room the heated air will ascend towards the ceiling; if you open a door into such a room and place a candle near the floor, the flame of the candle will lean inward, showing the direction of the air below. If you place the candle near the door-top, the flame will lean outwards, showing the escape of the warm air. In the centre of the doorway the flame stands upright. This simple experiment illustrates a great natural effect produced by the heat of the sun. The torrid regions of the earth are in the condition of our warm room. The heated air of the tropics rises and flows towards the poles, while its loss is supplied by an under-current of heavy air *from* the poles. Were the earth without diurnal rotation, these two currents would flow directly north and south; but, as is seen in the case of the Gulf Stream, the motion of the earth from the west to the east combines with the motion of the air from north to south, and thus we have, in the northern hemisphere for example, a south-westerly current above and a north-easterly one in the lower regions of the atmosphere. The lower current constitutes the trade-wind. But how do we know that the *upper* current exists? No man ever lifted a weathercock so high, yet still we may conclude with certainty that the under-current from the poles is balanced by an upper current towards them. But neither are we without experimental proof of the existence of the upper stream. I cannot, I think, better describe to you this experiment, made by Nature herself, than by translating the account of it

given by Professor Dove, while addressing a public audience in Berlin.

19. "On the night of the 30th of April," says M. Dove, "explosions like those of heavy artillery were heard at Barbadoes, so that the garrison of Fort Saint Anna remained all night under arms. On the 1st of May, at daybreak, the eastern portion of the horizon was clear, while the remainder of the firmament was covered by a black cloud, which soon spread over the east, quenched the light there, and finally produced a darkness so dense that the windows in the rooms could not be distinguished. A shower of ashes now descended, under which the tree-branches bent, and were broken. Whence came these ashes? From the direction of the wind we should infer that they came from the Azores: not so, however; they came from the mountain Morne Garou in St. Vincent, which lies about a hundred miles westerly from Barbadoes. The ashes had been cast into the upper current of the trade-wind, and thus borne forward in a direction opposed to the lower current. A second example of the same kind occurred on the 20th of January, 1835. On the 24th and 25th the sun was darkened in Jamaica by a shower of fine ashes, which had been discharged by the mountain Coseguina. The people learned in this way that explosions previously heard were not those of artillery. These ashes could only have been carried by the upper current, as Jamaica lies north-east from the mountain. The eruption furnishes also a beautiful proof that the ascending air-current divides itself above into two portions, one proceeding towards the North Pole, and the other towards the South; for ashes also fell upon the ship 'Conway' while in the Pacific, at a distance of seven hundred miles south-west of Coseguina."

20. Though the remainder of M. Dove's description does not strictly apply to our subject, still it is so interesting that I think you will not be displeased if I translate it for you:—

"Even on the highest of the Andes," he proceeds, "no traveller has as yet reached this upper current, and from this fact some notion may be formed of the force of the explosions: they were indeed tremendous on both the instances referred to. The roaring of Coseguina was heard at San Salvador, a distance of a thousand miles. Union, a seaport on the west coast of Conchagua, was in absolute darkness for forty-three hours; and as light began to dawn, it was observed that the sea-shore had advanced eight hundred feet upon the ocean, owing to the quantity of ashes which had fallen. The eruption of Morne Garou seemed to form the last link in a chain of vast volcanic actions. In the month of July, 1811, near St. Michael, one of the Azores, the Island Sabrina rose with smoke and flame from the bottom of the sea. The depth of water was a hundred and fifty feet, the height attained by the island three hundred feet, and it was a mile in circumference. The small Antilles were shaken afterwards, and subsequently the valleys of the Mississippi, Arkansas, and Ohio. But the elastic forces found no vent, and they next sought one on the north coast of Columbia. The 26th of March began as a day of extraordinary heat at Caraccas: the air was calm and the sky cloudless. It was a holiday, and a regiment of troops of the line stood under arms in the barracks of the quarter San Carlos, ready to join in a procession. The people streamed to the churches. A loud subterranean thunder was heard, and was immediately followed by a shock so violent that the Church of Alta Gracia, a hundred and fifty feet high, and supported by pillars fifteen feet thick, was reduced to a heap of rubbish not more than six feet in elevation. In the evening the nearly full moon looked down with mild lustre on the ruins of the town, under which lay the crushed bodies of upwards of ten thousand of its inhabitants. But even here the elastic forces found no outlet. Finally, on the 27th of April, they succeeded in opening the crater of Morne Garou, which had been closed for a century; and the earth, for a distance equal to that from Vesuvius to Paris, rang with the shout of the liberated prisoner."

LESSON XVIII.

CONDUCTION AND RADIATION.

1. On the conduction of heat.—If you thrust one end of a poker into a fire, the heat will propagate itself through the metal and finally make itself felt at the other end. This travelling of the heat from particle to particle of the iron is called the conduction of heat, and the metal itself the conductor. You will observe here, at the outset, that this is a very different process from that by which heat, as already described, distributes itself through a liquid. This process is sometimes called *convection ;* the heated particles, it will be remembered, rise and diffuse their heat through the cooler ones; but there is no such wandering of the particles in the case of the poker. When a column of liquid is heated at the top, the propagation of heat through it is immeasurably slower than when it is heated at the bottom, for the warm layer of liquid remains at the top, and must thus communicate its heat to the lower ones by the process of conduction, and not by that of convection. With the poker it is immaterial whether you thrust it upwards, through the bars, or downwards; the heat will propagate itself alike from the hot end to the cold one.

2. Metals are the best conductors of heat, but they differ widely from each other in this respect. The first experiments made to determine this conductibility were very defective, nevertheless a certain celebrity still attaches itself to those of Ingenhousz. He coated a number of different bars with wax, and dipping one end of the bars into a bath of hot oil, he was able to trace the progress of the heat by the melting of the wax upon the surface. M. Despretz, however, was the first to

confer experimental accuracy upon this branch of science. He took bars of various metals, and arranged

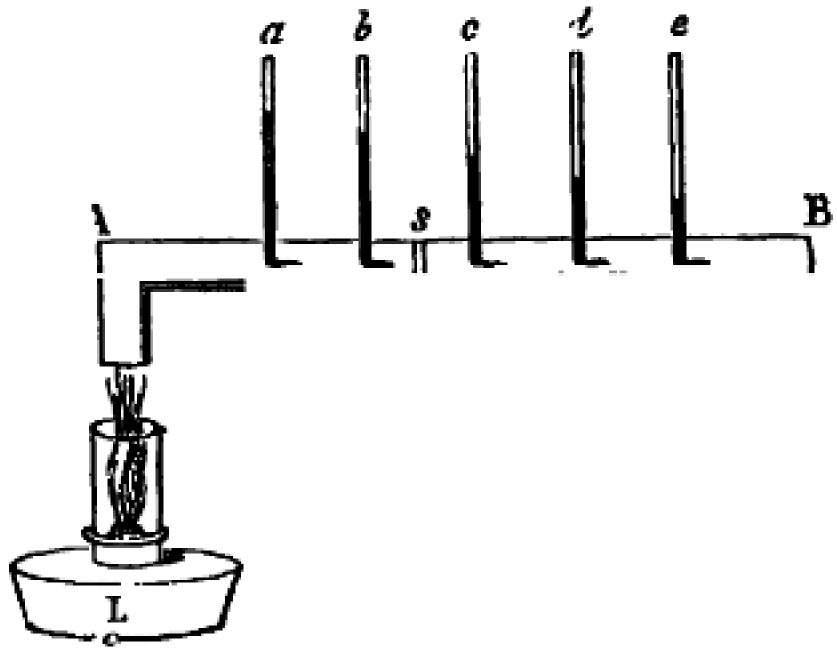


Fig. 14.

each of them as A B in fig. 14. At one end is a lamp L, the flame of which is preserved constant; this communicates heat to the end of the bars: at equal distances asunder, and fitting into cavities made in the bar, are the thermometers *a*, *b*, *c*, *d*, *e*. The heat imparted by the lamp travels through the bar, and the mercury in the thermometer *a* is soon observed to rise; *b* is next affected; the heat reaches the others in succession, and causes them to rise. Fix your attention upon any slice taken across the bar, say at *s*. This slice receives heat from the end A of the bar, and sends it on to the end B. As long as the quantity received from A exceeds that given up to B, the temperature of the slice will increase; but after a sufficient time these quantities will become exactly equal to each other, and thus, though there is a flow of heat through the slice, its temperature remains constant. M. Despretz waited until this condition had established itself throughout the whole bar: his thermometers then ceased to rise; the mercury then stood highest in *a*, and lowest in *e*, gradually diminishing from one to the other. From this he was enabled to calculate, and express in numbers, the conductibility of each bar for heat.

3. The following are the results of the most recent experiments made upon this subject:—

Substances.	Conductibility for Heat.	Conductibility for Electricity.
Silver	100	100
Copper	73·6	73·3
Gold	53·2	58·5
	23·6	21·5
Tin	14·5	14·0
Iron	11·9	12·0
Steel	11·6	„ „
Lead	8·5	8·27
Platinum	8·4	7 93
German Silver	6·3	5·9
Bismuth	1·8	1·9

Thus silver stands at the head of the list of metallic conductors and bismuth at the foot. The numbers in the second column express the relative conductive powers of the metals used. I have also added a third column, which shows the conductive powers of the same substances for electricity; and here the suggestive fact will be observed, that the best conductors of the one agent are also the best conductors of the other.

4. Next to the metals, crystals, stones, glass, and similar bodies are the best conductors of heat, but they differ as much among themselves as the metals do. A crystal of quartz, for example, has a conductive power greatly superior to that of a crystal of gypsum: rock salt conducts heat much better than sugar. Flint conducts better than marble. It is perhaps worthy of remark that substances which belong to the animal and vegetable kingdoms are extremely imperfect conductors; and both animals and vegetables are in some measure protected by this property from the injurious effects of sudden changes of temperature.

5. I have already referred to the fact that in a cold room, metals, when touched by the hand, seem coldest, and the woollen fabrics least cold. We are now in a

condition to understand this. The metal is a good conductor, and diffuses the heat communicated to it by the hand quickly through its mass, it thus abstracts the heat speedily from the hand and produces the sensation of cold. Wool, on the contrary, cannot thus dispose of the heat; the superficial layer in contact with the hand is all that the hand has to warm, and the quantity of heat necessary for this is almost inappreciable.

6. You will sometimes see metallic pipes used for the conveyance of steam, and which it is desirable to keep warm, wrapt round with straw bands, coarse flannel, or some other similar material. Were the pipe in contact with the atmosphere it would yield up its heat quickly, but the interposition of the non-conducting material prevents this. Precisely in the same manner the interposition of non-conducting woollen cloth saves our bodies from the abstraction of heat by the chill of the atmosphere. The philosophy of wooden handles to coffee-pots and kettles, the reason why a piece of ivory is interposed, where it is deemed desirable to have a metallic handle to a teapot, and other things of the same kind, will be so evident to you as not to need a word of explanation.

7. Not only do different bodies possess different conductive powers for heat; but in some cases the same body possesses different powers in different directions. Many crystals exhibit this peculiarity. Wood also exhibits it. If the surface of a plate of wood be thinly coated with wax, or with stearine, and a wire be introduced through a small hole in the plate, and heated while in this position, the heat passing from the wire into the wood will melt the wax; but it will not melt it equally well in all directions. Let *a*, *b*, *c*, *d* (fig. 15), be such a plate of wood, and *h* the aperture in which the wire is inserted; the heat passes most

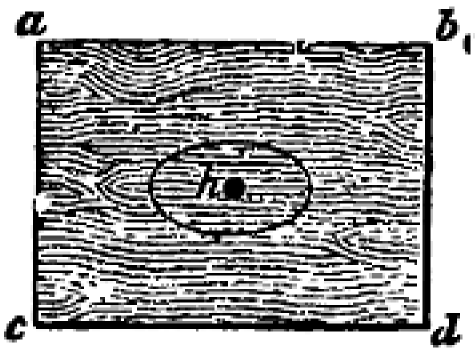


Fig. 15.

freely in the direction of the fibre of the wood, which in the figure is parallel to the sides *a b*, and *c d;* the consequence is that the melted wax forms an oval, with its length along the fibre. If the wood conducted equally well in all directions, the figure melted away would form a circle.

8. I cannot quit this subject without pointing out a very common mistake made in treatises on Natural Philosophy, and repeated by lecturers upon heat. To illustrate the different conductive powers of different bodies, short cylinders of these bodies are taken and placed upright upon a heated surface—for example, upon the flat lid of a metallic vessel containing boiling-water. A bit of wax or of phosphorus is placed upon the upper end of each cylinder, and it is stated that the cylinder on which the wax is first melted, or the phosphorus first ignited, is the best conductor.

Now, if two cylinders an inch in length, one of iron and the other of bismuth, be each furnished with its bit of phosphorus, and placed at the same instant upon the heated surface, it will be found that the phosphorus upon the bismuth ignites sooner than that upon the iron. Hence, according to the lecturers and books referred to, bismuth ought to be a better conductor than iron. By reference to our table at page 143, it will, however, be seen that bismuth is greatly inferior to iron as a conductor of heat; it stands lowest among the metals, and is actually less endowed in this way than some non-metallic bodies. How then are we to reconcile this apparent contradiction?

9. In fact, when such a mode of experiment was adopted, it was wholly forgotten that something else than mere conduction came into play and modified the result. It is undoubtedly true that the greater the conductive power of our cylinder, the greater will be the quantity of heat taken up by it in a given time from the hot surface upon which it rests, and thus iron will take up more heat than bismuth. But if you look at the table at page 120, you will see that while iron possesses a

specific heat of 0·11379, the specific heat of bismuth is only 0·03084. What is the consequence? Why, that though bismuth takes in far less heat than iron, yet on account of the low specific heat of the former metal, the small quantity which it takes in heats it considerably, and thus produces a speedy effect upon the phosphorus. I am the more induced to call your attention to this, from the fact that during a recent public examination nineteen out of twenty-two candidates, misled by what they had heard in lectures and read in books, fell into the error of supposing that the experiment to which I have referred was a true test of conduction. The proper way would be to wait until the body has taken in as much heat as it can: that body then which is heated to the greatest distance is the best conductor.

10. ON THE RADIATION OF HEAT.—If you stand before a fire without touching it, you feel heat, and if a goose be suspended before it, you may, without at all bringing it into contact with the fire, roast the goose. Here there is no conductor between the goose and the fire, yet the heat reaches it and cooks it. You may reply that there is air between both, and that *it* may be the carrier of the heat. But you may allow a current of air to pass across between both; you may blow with a pair of bellows between them; you blow away the air, but you cannot blow away the heat; it will cross the current of air and reach the goose as before. Nay, you might by suitable means take away the air altogether, and still find that the heat would cross the vacuum. Heat which thus travels without the interposition of a conductor is called *radiant heat:* it passes from a warm body exactly as light is radiated from a luminous one.

11. There is a striking analogy between the action of radiant heat and of light. Heat can be reflected like light; it can be refracted, it can be polarized. You can cause two rays of light so to act upon each other that they shall mutually destroy each other's actions, or, in other words, by adding light to light you can produce darkness; and so in like manner by adding heat to heat

you can produce cold. For the meaning of the terms which I have here used, I must refer you to the article upon Light. We soon notice striking differences in the manner in which this radiant heat is received by different bodies, some bodies absorb it greedily, others reject it, those bodies which absorb it greedily also radiate it plentifully, while those which do not absorb it readily are feeble radiators. The metals, though the best conductors, are the worst radiators, and instead of absorbing radiant heat, they reflect it. If you place a bright silver teapot containing cold water, before a fire, the water will warm with extreme slowness, for nearly all the heat that falls upon the teapot is reflected. If the same teapot be coated with lamp-black, or even with a thin sheet of varnish, the warming of the water will be immensely accelerated, for the coating absorbs the heat and communicates it to the metal. Let us now reverse the experiment. Let two teapots, one polished and the other coated with lamp-black, be filled with hot water, and let a thermometer be immersed in each. It will be found that the water in the blackened vessel cools more quickly than that in the polished one. This effect is not due to the abstraction of heat from the teapot by the cold air; were this the case the bright teapot would be chilled quickest, for the lamp-black is a bad conductor, and thus tends to check the flow of heat to the air. The quicker cooling of the blackened vessel is due solely to the fact that the lamp-black, though it conducts much worse, radiates much better than the metal.

12. A very thin film on the surface of a body is sufficient to alter its power of absorption and radiation. Let the quantity of heat radiated by clean lead be 19; the same lead, when tarnished by contact with the atmosphere, will radiate a quantity expressed by the number 45, or nearly 2½ times as much as before.

Experiments on this subject may be satisfactorily performed with the air thermometer of Leslie. A description of the best instrument would necessitate a knowledge of certain electrical actions, and therefore such a description cannot be introduced here.* The air thermometer is represented in fig. 16. It consists of two thin glass bulbs, united by a tube bent as in the figure. The bent tube contains a coloured liquid, which stands, let us suppose, in one leg at *a*, and in the other at *b*. If heat be communicated to the bulb above *a*, the air within it will expand, press down the surface *a*, and lift the surface *b*; the descent of the liquid is measured by a scale which is attached to the instrument. Air, as we know, is much more expansible than mercury, and the thermometer here described is proportionally more sensitive than the mercurial thermometer.

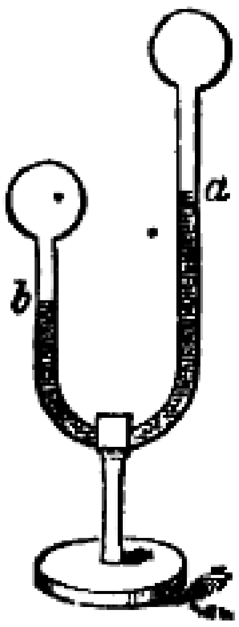


Fig. 16.

13. Radiant heat is subjected to the same laws of reflection as light and sound. I have in a former article described the parabolic mirror, and would now recommend you to turn to the place and refresh your memory upon the subject. Let A B (fig. 17), be such a mirror,

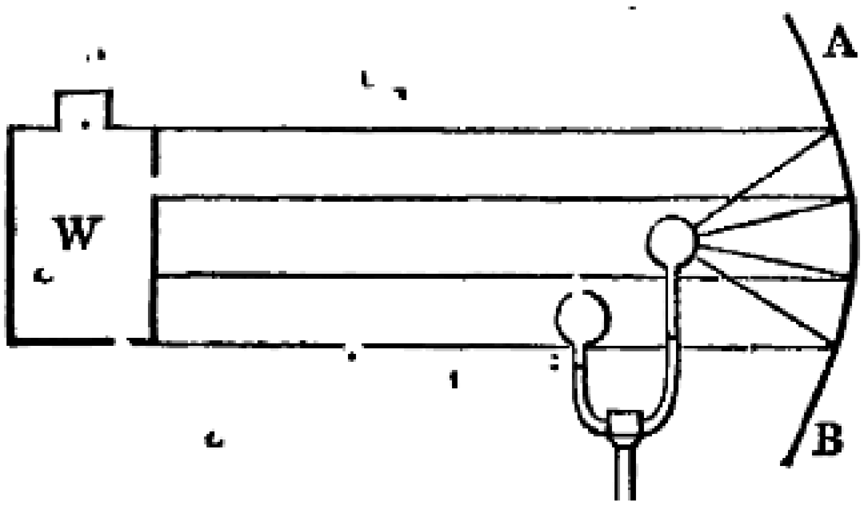


Fig. 17.

and let W be a cubical vessel filled with hot water. The parallel rays of heat which proceed from W are all collected to a point by the mirror A B, and if the bulb of the air-thermometer be placed in the focus, the liquid in the stem underneath it will immediately sink. If one side of the cubical vessel be kept bright, and another be coated with lamp-black or white-lead, it will be seen, on turning the coated surface towards the mirror, that the depression of the liquid is greater than where the heat radiates directly from the metal.

14. In lecture experiments, two such mirrors are commonly used. Let a hot sphere of metal be placed upon the stand in the focus of the mirror A' B' (fig. 18), the heat will be reflected from A' B' in parallel lines, and will be collected by the mirror A B into its focus. If the bulb of the air-thermometer be placed in this focus, the liquid column underneath will be forcibly depressed. That this is due to the reflected heat, and not to the heat falling directly from the ball upon the thermometer, may be proved by causing the thermometer to approach the ball; if the action were due to the direct heat, the depression of the liquid would be augmented, but the contrary is observed; when the bulb quits the focus, the liquid rises.

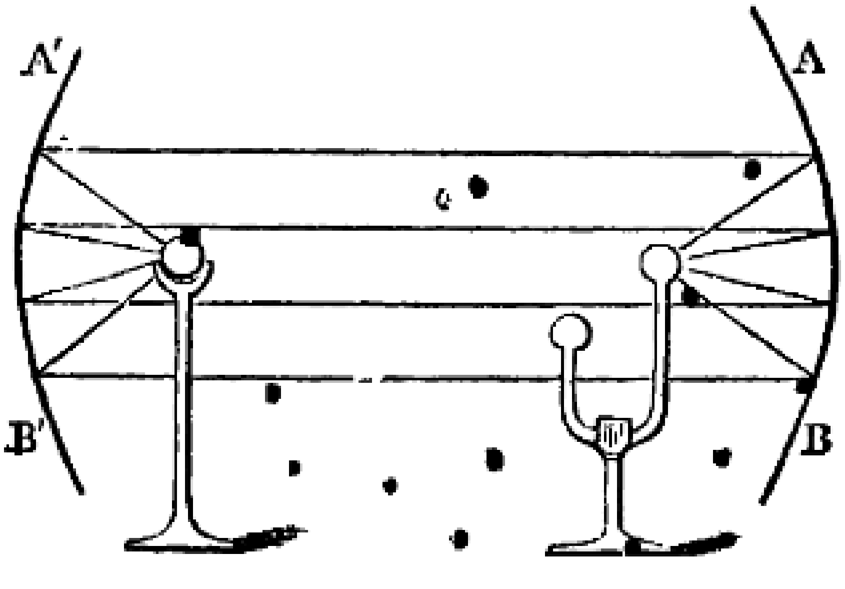


Fig. 18.

The mirrors, when large, are sometimes placed one above the other; one, for example, is placed on a table, and the other drawn up to the ceiling by means of a rope and pulley. Placing a red-hot ball in the focus of the upper mirror, a lucifer-match may be ignited, and some other inflammable substances caused to explode:

or even a fowl might be roasted, by placing it in the focus of the lower mirror.

15. Let me now endeavour to apply the knowledge which we have gained to the explanation of a beautiful natural phenomenon—the formation of Dew. On a fine autumn morning you may see the grass-blades loaded with liquid pearls, while metals and other bodies exposed to the night-air remain quite dry. Let us prepare the way for the explanation by calling to mind one or two facts. The pure vapour of water is as transparent as the air; and when I stated, in describing the Geyser eruption, that the water was wrapped in clouds of steam, I expressed myself popularly, but not with scientific accuracy. This visible cloud is not steam, but water in a fine state of division: fog, in like manner, is not vapour, but a collection of water particles: pure steam or vapour, it must be remembered, is transparent, and invisible in the air.

The warmer the air is the greater is the quantity of vapour which it can preserve in this transparent state. During some days of great serenity, especially in autumn, the air contains a large quantity of transparent vapour, and it is in the nights of such days that dew is deposited most copiously: you will find no dew deposited on a cloudy or a windy night.

16. Imagine, then, a meadow lying at night under a serene sky. The heat imparted to the grass-blades during the day is now sent off from them by radiation; they are excellent radiators, and send out the heat they possess lavishly into space. Were clouds in the heavens, they would intercept and return a portion of the heat sent out, and thus protect the grass from being chilled; but when no clouds exist, it is a case of pure loss, as far as the grass is concerned; the heat once radiated returns to it no more.

Grass is also a very bad conductor, and it is therefore unable to draw from the earth on which it grows a supply to make good its loss by radiation. The consequence is, it becomes more and more chilled; and if you place a thermometer among such grass, you will always find its temperature lower than that of the air a few feet above the meadow.

The little grass-blades thus chilled condense the atmospheric vapour upon their surfaces. The warmth gained by the precipitation of the moisture is again radiated, and thus throughout the night the grass is kept cold. The process of condensation continues, and the quantity of moisture deposited is at length so great that we see it in the morning as shining pearls weighing down the blades of grass. What has been said regarding grass applies especially to those fine cobwebs which we see in the country hedges; they also become chilled, and liquid spherules are ranged like beads along the tiny threads.

17. NOTE ON THE NATURE OF HEAT.—In the foregoing article I have alluded to what is called the material theory of heat. Within the last few years scientific men have more and more seceded from this theory, and the belief is now gaining ground that heat is not a kind of matter as once supposed, but that it is a motion of the particles of matter. A vibrating string or bell communicates its motion to the atmosphere; the motion reaches our ears and produces the sensation of sound. A luminous body is supposed to be also in a state of vibration, and its motion is transmitted, not by air, but by a finer medium, called ether, to the nerve of the eye, thus producing the sensation of light. So, also, a warm body is one whose particles are in a state of vibration, communicating this motion also to the ether, and producing, when they strike the proper nerve, the sensation of heat. The waves or undulations excited in the ether by a warm body differ from those produced by a luminous body, by being of greater length and of longer duration. The same ray may, by falling upon one nerve, produce the sense of light, and by falling upon another, produce the sense of heat. The sunbeams probably act in this way. The molecular motion which we call heat may be produced by mechanical

means. Every time that ordinary mechanical motion is destroyed or retarded, heat is developed. When a stone falls to the ground, or a cataract casts its waters over a ledge of rocks, the checking of its motion upon striking the earth is accompanied by the development of an amount of heat exactly equivalent to the quantity of motion destroyed. By the compression of air you can produce heat sufficient to ignite tinder. In some books the air is described as a sponge holding the heat within it; and it is said that the heat is squeezed out by the act of compression. The new view says, "No! it is the mechanical force exerted in compressing the air that has thrown the particles into the motion that we call heat." We know exactly how much heat is developed by the expenditure of a given amount of force. We can calculate the quantity of heat generated by a cannon-ball on striking a fortress, if we know the velocity of the ball. We know that if our earth were brought by a shock to a state of rest in her orbit, the amount of heat generated would be equal to that produced by the combustion of fourteen earths of solid coal; and if afterwards the earth fell into the sun, which she would do if her orbital motion were destroyed, the amount of heat generated by the shock would be four hundred times greater. I cannot enter fully into this subject here: it is new, and not quite suited for boys. Nevertheless, I was unwilling to leave you in ignorance of the notions now entertained regarding the nature of heat. The material theory is, as I have said, losing ground more and more; and it is probable that in a few years it will not number among its adherents a single individual whose opinion is of any authority in science.

LIGHT. BY ROBERT HUNT.

LESSON XIX.

RADIATION.

1. **Light.**—The alternations of day and night, regulated by the appearance and disappearance of the sun, must prove to every one that a most intimate connection exists between the phenomenon of LIGHT and that enormous orb around which the earth revolves. Our world is a spheroid, which, having a motion around its axis, is regularly advancing one section of its surface towards the sun, while a corresponding portion is as uniformly receding from it. To the inhabitants of that division which is advancing, the sun is said to be rising; it is morning, and the industrious begin the labours of the day. To the men who dwell upon those lands which are receding, the sun is regarded as setting—the quiet of evening invites them to repose—sleep naturally following the loss of light. If we suppose the larger circle in the accompanying figure (1) to represent the sun and the smaller one the earth, then admitting the former to be the source of illumination, and the latter the recipient of the light, a very brief consideration of motion around an

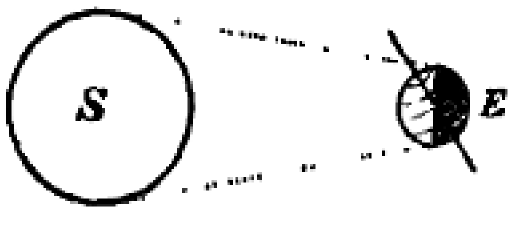


Fig. 1.

axis in the smaller body will render the fact evident, that the side of the earth facing the sun will be in daylight, while the other hemisphere will be under the cloud of night. With those variations in the length of the day and night—in the duration of light and darkness—which are dependent upon the annual motion of the earth around the sun—the Seasons—it is not proposed to deal in this section.

2. The sun is the great original source of light to the earth; our satellite, the moon, is but as a mirror, reflecting some of the solar rays back to us, and all the planets, of our system, shine in the blue vault above, but by reflected beams. Many of the fixed stars, however, are suns shining with their own light, and illuminating other spheres with their rays, as our sun pours all the blessings of light upon our earth. We say the sun is the source of light, yet we have to confess our ignorance of what this principle or agent is by which we see. We know it by its effects—the *cause* which produces these effects is, apparently, beyond the reach of human intellect. An important problem, connected with the source of this illuminating power, has received a satisfactory solution. It was desirable to determine if the light of the sun came from a mass of solid matter intensely heated, or from a gas in some condition of combustion. By having previously examined into the nature of the light proceeding from a sphere of white hot iron, and that which is propagated from a gas-flame, certain facts connected with the phenomena, known as the polarization of light—to be hereafter explained—were determined; and these have enabled the astronomer to prove that the light of the sun is derived from a gaseous envelope, to which has been given the name of the *photosphere* or light sphere.

3. Artificial light can be produced in various ways, which it is important to remember. By hammering a piece of iron briskly it soon becomes hot, and eventually it grows *red hot*, or gives out *red light*. By rubbing pieces of dry wood together we may set them

on fire; that is, we develop *heat* and *light*. All bodies, whatever may be their character, begin to emit light at the same temperature; and whether the experiment is tried with a piece of inflammable paper, a bar of iron, or a block of stone, they equally begin to shine with light when they acquire a temperature, indicated by about 1000° on the scale of Fahrenheit's thermometer—and not before.

4. Violent mechanical disturbance occasions then the development of this principle, whenever powerful chemical changes occur, we have luminous phenomena, and the excitement of electricity gives rise to extraordinary manifestations of light. Phosphorescence, as it is called, or the shining of phosphorus in the dark, and the evolution of light from decaying vegetable and animal matter, is due to chemical changes; and the phosphorescence of living animals is probably due to the same cause, under the influence of nervous excitement.

5. Such being the conditions under which we know light to be produced upon this earth, it becomes probable that one or more of these causes may be active in maintaining the disturbance, which appears necessary, to secure the continuance of that unceasing flood of light which the earth and the other planets receive from their solar centre.

6. Supposing we are in a dark room, and a point of light, such as a small taper, is introduced, all the bodies in that apartment are more or less illuminated. The rays from the taper spread in every direction, and enable the eye to distinguish objects, by the reflection of these rays from the surfaces upon which they fall back to that organ of vision. Here we have two striking facts—the passage (*transmission*) of light in radiant lines, or *rays*, in every direction from the source of illumination, and the turning back of these rays, or their *reflection*, from the bodies illuminated. This we must endeavour to comprehend. Instead of employing a candle as our source of light, let us admit a fine sunbeam through

a small hole into the dark room, a white spot of light will appear upon the floor, and the apartment is partially illuminated thereby, because the surface of the floor reflects the rays to the ceiling and walls. But if we place, to receive the ray, some body which has but very slight powers of reflexion, such as a piece of black velvet, and adopt the precaution of preventing any radiations, except the direct sun-rays, from entering the hole, the result is that the room remains dark, except the small round spot of light formed upon the velvet. If we place a sheet of white paper to receive the ray, it will be *dispersed* and reflected from that surface; and if we use a polished piece of steel or a looking-glass, we shall throw an image of the spot of light, upon the wall, exactly corresponding to the image formed on the floor. In the first example nearly all the light is *absorbed* by the black velvet; in the second it suffers *dispersion*, is reflected in all directions; and in the third is *reflected*, with but little dispersion, along a well-defined line.

7. Light, therefore, is liable (1.) to be *absorbed* by some substances, (2.) it undergoes *dispersion* in different degrees from others, and (3.) it is *reflected*, either entirely or partially, from such as are capable of receiving a high polish.

8. The round spot formed upon the floor is an image of the disc of the sun. If the eye, protected from injury by a piece of dark glass, is placed in the path of the ray, the whole image of the sun will be seen; or if the experiment is made during an eclipse of the sun, the image formed will exactly correspond with that of the bright portion of the sun, the other parts being cut off. This may be simply illustrated. Take a lighted candle, fig. 2, and having made a fine pin-hole in a piece of card-board, place it in such a manner that the rays from the candle pass through the hole and fall upon a screen—an inverted image of the candle will thus be formed upon it. From every point of the flame, *light* has passed through the pin-hole in straight lines, so that the hole is the vertex of a cone prolonged in both directions. The

image of the sun is produced in the same manner; and

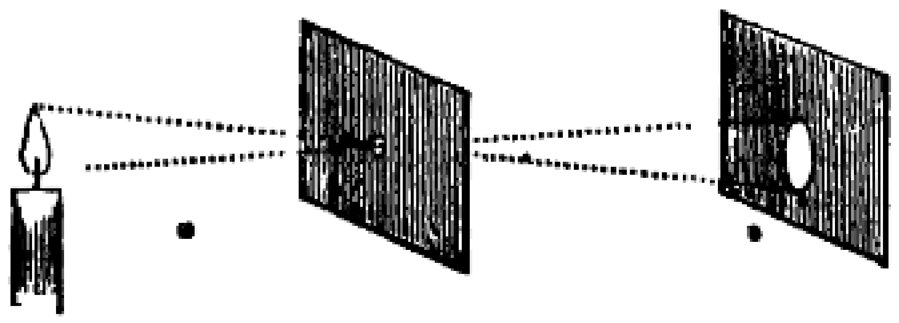


Fig. 2.

the beautiful pictures formed in the camera-obscura, or dark chamber, are dependent upon these conditions.

9. Light, therefore, progresses in straight lines from every part of any luminous body. For its progress *time* is necessary. If a point of light is suddenly extinguished, and two observers are at different distances from it, it will not disappear to each at precisely the same time. The velocity is too great to render this appreciable in any experiment of an ordinary kind on this earth, but some astronomical phenomena render it quite evident. The planet Jupiter has several moons, which are often eclipsed by, or eclipse portions of the planet, accordingly as they pass behind it or over its disc. Now Jupiter varies greatly in its distance from the earth; the periods when these eclipses and emersions take place are exactly known, and it is found that they become visible nearly fifteen minutes sooner when the planet is at its least, than when it is at its greatest, distance from us. While a ray of light is passing from any of the stars to the earth, the earth is moving onward in its orbit round the sun, consequently between the time when the ray leaves a star, and when it reaches the eye of an observer on the earth, the latter will have shifted his place, and the star will consequently appear removed from its true place in the direction in which the earth is moving. This astronomical phenomenon is called the *aberration of light*, and observations founded on it confirm the results obtained by those of the eclipses and emersions of Jupiter's satellites, viz., that

light travels at the enormous velocity of 191,515 miles in a second of time. To form some idea of this velocity it will be sufficient to conceive a cannon ball fired with the greatest force from the sun, and continuing its velocity unabated till it reaches the earth, it would require more than seventeen years to traverse the space over which a ray of light passes in seven minutes and a-half. Notwithstanding this high velocity, it has been demonstrated, that, if the nearest of the fixed stars were suddenly extinguished, we should not notice its disappearance for five years, the last ray of light leaving it requiring that time to pass through the intermediate space.

10. Light radiating from any luminous body, diffuses itself as the distance from its source increases. This is capable of easy illustration in this way. Let a candle, fig. 3, be placed behind an opaque screen in which are

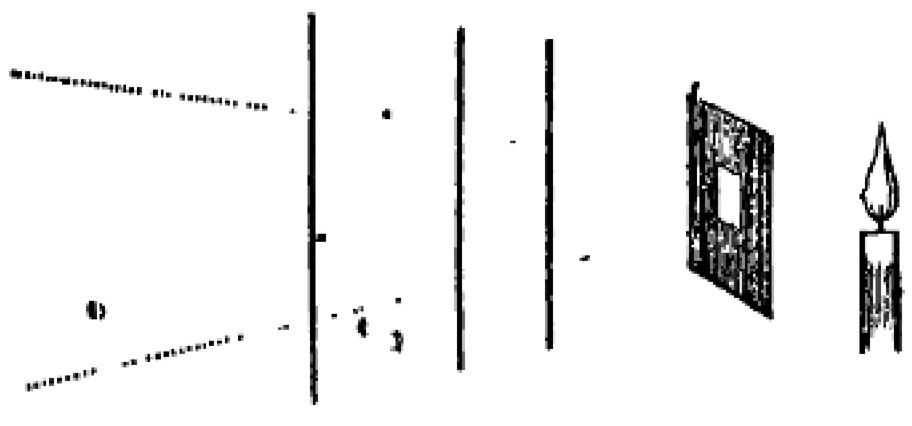


Fig. 3.

pierced a number of holes over one square inch of its surface. Now, upon a sheet of white paper placed immediately behind the screen we shall see specks of light marking out a square inch. As the sheet of paper is removed further from the screen, the space illuminated increases, and at the same time the intensity of illumination diminishes. And if we remove the paper to regular distances we shall discover that this increase being, indeed, as the squares of the distances from the vertex, indicates a diverging pyramid of rays..

The shadow of any body, larger than the source of light by which the shadow is produced, in like manner enlarges uniformly with the increase of distance. But if the body is smaller than the illuminating source, the shadow as regularly diminishes.

11. Photometers—as instruments employed for measuring the relative illuminating powers of lights are named—are usually constructed upon the principle of measuring the distances necessary to produce equally bright spots of light upon a screen, or equal intensities of shadow. For example, it is desired to know the illuminating power of a gas-flame as compared with that of the flame of a wax candle. If they are placed, fig. 4, side by side, and the light from each is made to pass through a hole in a screen, and fall upon a white sheet of paper, placed to receive it, two spots will be formed, one spot will appear very much brighter than the other, the candle being kept at the same distance from the paper, the distance between it and the gas-flame is increased, until the two spots of light are of precisely the same character; the difference then between the distances of the two illuminating bodies will give the measure of their relative intensities. By a little ingenuity, it will be seen, the arrangements of a photometer may be greatly varied—so as to render the instrument portable and its indications easily understood. Light progresses in straight lines when traversing any homogeneous medium, but if there is any variation in the density of the media through which it passes, as in air, water, or glass, it is bent or *refracted* out of its former path. Or, if any medium is interposed in the path of a ray, which will not allow of the transmission

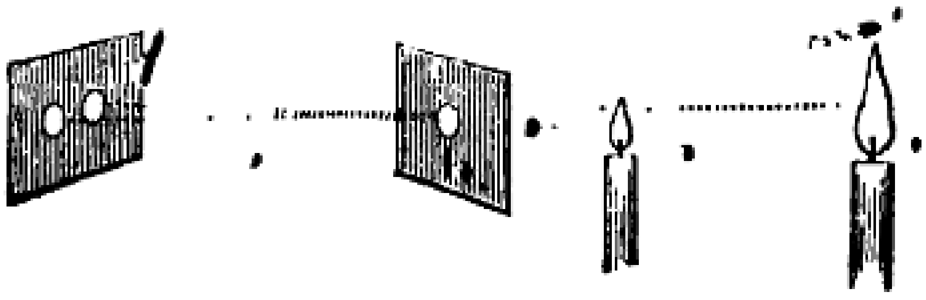


Fig. 4.

of light, it is then turned back, or suffers *reflexion*. As many very important phenomena depend upon the *refraction* and *reflexion* of light, the laws which regulate these conditions must be understood.

LESSON XX.

REFRACTION AND REFLEXION OF LIGHT.

1. REFRACTION, a term derived from the Latin, signifying *breaking* back, takes place whenever a ray of light passes from one medium, as air, into another which is denser than it, as water—or the contrary. When we view a body under water, we do not see it in the place which it actually occupies. If the spot A, fig. 5, were a white stone at the bottom of a pond, an observer at B would perceive its image at C; supposing this line BC to be continued—as by a rod with which we desire to strike the stone—it will fall at *a*. An instructive experiment, is to place a coin in the bottom of a basin, and then retiring so far from it, that the edge of the basin prevents the eye from seeing the coin, request an attendant to pour in water, steadily, without removing the coin; when the fluid rises to a certain height the coin will again become visible. If the line B *a* in the figure represents a stick placed in air and water, it will appear as if broken at *d* from the same cause.

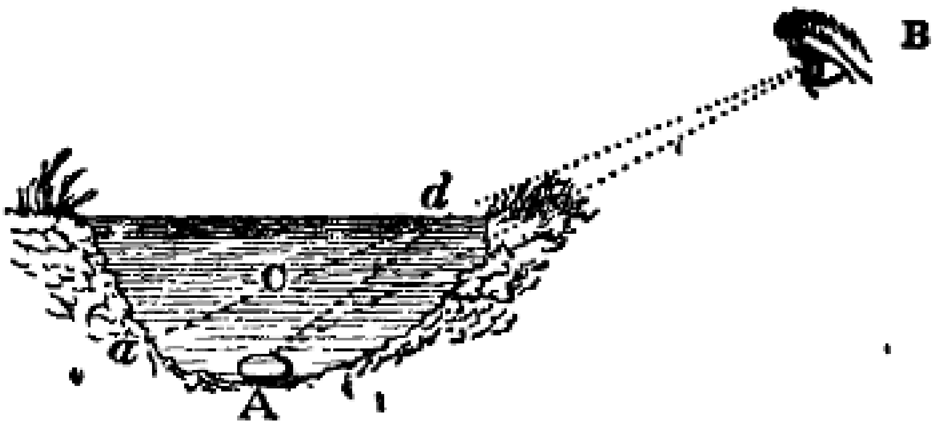


Fig. 5

2. If a ray of light falls perpendicularly upon a transparent body, as a plate of glass, (fig. 6,) it passes through, without suffering refraction as the line A *b c* which we suppose to pass through a piece of glass with parallel faces. If, however, a ray B *b* falls at any angle upon the surface it is bent to *d*, and on emerging again into the air, it will be again refracted in a direction *d e* parallel to B *b*.

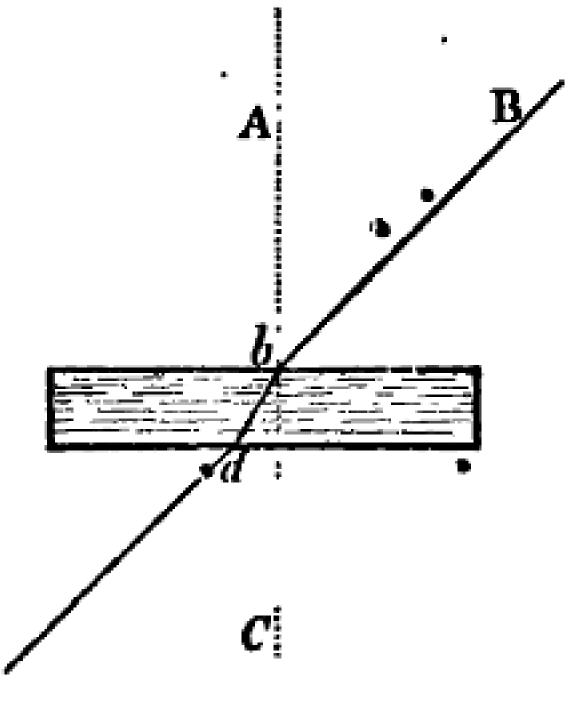


Fig. 6.

3. It will now be understood that a ray of light, while it is passing through a medium of unvarying density, suffers no deviation from a straight line, but that in passing from one medium into another, differing, howsoever slightly, in density, it is bent. The law being that *when light passes out of a rare into a dense medium the angle of incidence is greater than the angle of refraction; and when light passes out of a dense into a rare medium, the angle of incidence is less than the angle of refraction.* The twilight of our climate is entirely dependent upon the refracting power of the air. The suns sinks below the horizon *a a*, (fig. 7,) but its rays still fall upon the upper regions of the air. They are there bent in upon the next denser stratum of air, and still more so in passing into the next, so that at A the sensation of light is experienced, long after the sun has set, as long, indeed, as the direct rays of the sun can reach that portion of our atmospheric envelope indicated by B in the diagram. Many other remarkable natural phenomena, as mirage, the apparent

elevation of sea-coasts, halos, and the rainbow, are due to refraction. The production of colour by refraction will form a subject for consideration in a future page.

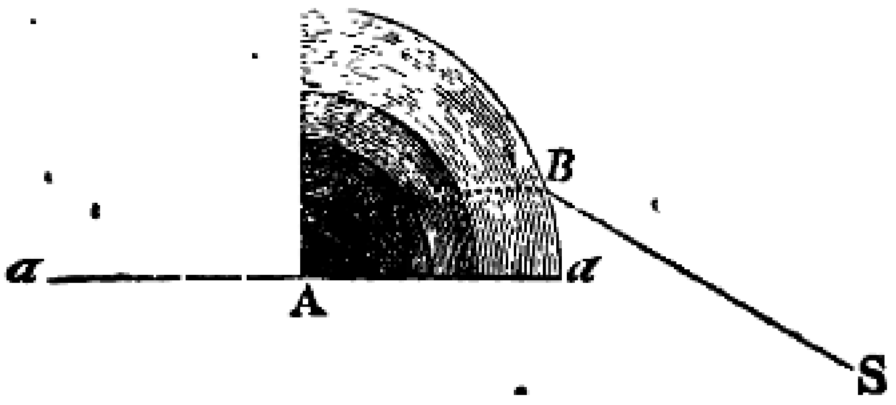


Fig. 7.

4. The properties which lenses possess of enlarging any object, as in the glasses of spectacles, of the microscope, or of the telescope, are entirely due to the phenomena of refraction. The consideration, however, of the laws of refraction, from spherical surfaces, belong more especially to that section of our work which we have devoted to optics and optical instruments.

5. Reflexion.—If we look into a silvered-glass, a polished plate of metal, or a pond of still clear water, we see our own image. This is due to *Reflexion*. The radiations, from the surface of the body, illuminated by solar or artificial light, are reflected from the surface upon which these rays fall. But let us examine the condition with a single source of light, such as a taper, A A (fig. 8.) If M M is a mirror of

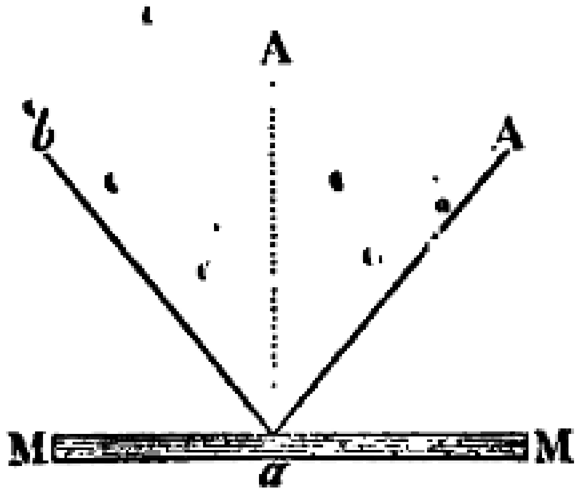


Fig. 8.

any kind, and A is placed so that its rays fall perpendicularly A *a*, they are all reflected back along the same line. If, however, the taper is placed at A, and its rays are incident at the point *a*, they then suffer reflexion to *b*. The eye being placed at *b* would perfectly see the image at A, which, supposing it was a single ray of light admitted through a hole at A, and totally reflected, would not be seen at any other point. The line A *a* is called the *angle of incidence*, and the line *a b* the *angle of reflexion*. We therefore say the *angle of incidence and the angle of reflexion are equal, but on contrary sides of the perpendicular.* Accordingly as we vary the form of the reflecting surface so we alter the size of the reflected image, but the above law of reflexion is equally true for curved as it is for plane surfaces.

6. Under the influences of the laws of reflexion and refraction all the blessings of light which we enjoy are determined. The eye (fig. 9) is a beautifully-constructed refracting instrument, by which the rays from external objects are brought to a focus on a peculiarly-sensitive tablet, on which the images are painted, and upon which, indeed, we *see* them. The eye being merely the instrument into which the mind *looks*, and discovers the objects, by which the individual to whom it belongs, is surrounded. Accordingly as the various surfaces of the organic and inorganic bodies in nature have the power of absorbing, reflecting, and refracting the rays

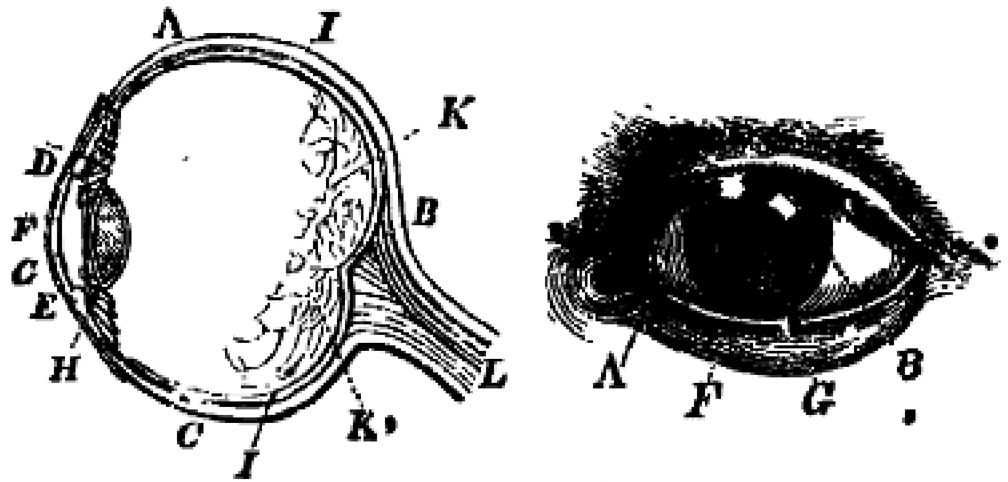


Fig. 9.

of light, so are they coloured to our perceptions. There are no substances which possess an innate colour. The colours of flowers, which give so much beauty to the garden, the tints which the dyer produces upon textile fabrics, and the hues which the painter employs to embody on the canvas the conceptions of his genius, are all alike due to a *surface action*, by which some rays are sent to the eye, while others are absorbed.

7. The phenomena of colour now claim our attention. The boy blows his soap bubble, and is delighted to witness, as it floats in the air, the beautiful play of colours upon its surface. A drop of yellow oil, or of spirit varnish falls upon water, and as it spreads upon the surface of the liquid, it passes through a variety of the most intense colours. Thin films of glass, or of mica, give similar colours. Sir Isaac Newton was the first to investigate these chromatic phenomena, and he shows that at certain thicknesses all transparent bodies possess this power of decomposing white light into coloured light, each particular colour, for the same medium, depending upon the thickness of the film. By placing two lenses, as *a a'*, (fig.10), a plano-convex lens, and A A', a double convex lens together, it is obvious they can only touch at one point, and that around that point the space regularly increases in size. By means of screws, these surfaces can be squeezed closer together, and thus are produced a series of coloured rings dependent on the thicknesses of the film of air: the curvature of the lenses being known, the thickness of the film producing any colour can be determined. The tenuity of these films is so great that their thicknesses can only be reckoned in millionths of an inch. These vary from 1 millionth to 77 millionths.

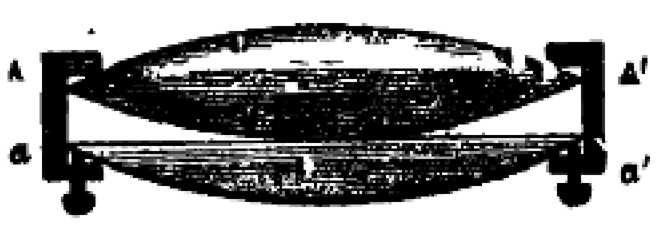


Fig. 10.

8. The colours produced by fibres and by grooved

surfaces are the result of analogous conditions. Our space will not allow of our entering into the consideration of these, we therefore proceed to the analysis of a ray of white light by prismatic refraction.

9. If we allow a pencil of sun-light to pass through a small hole into a darkened room, after the manner previously described, and place a triangular piece of glass—which we call a prism—so that the rays fall upon the first surface A B (fig. 11), and emerge at its second

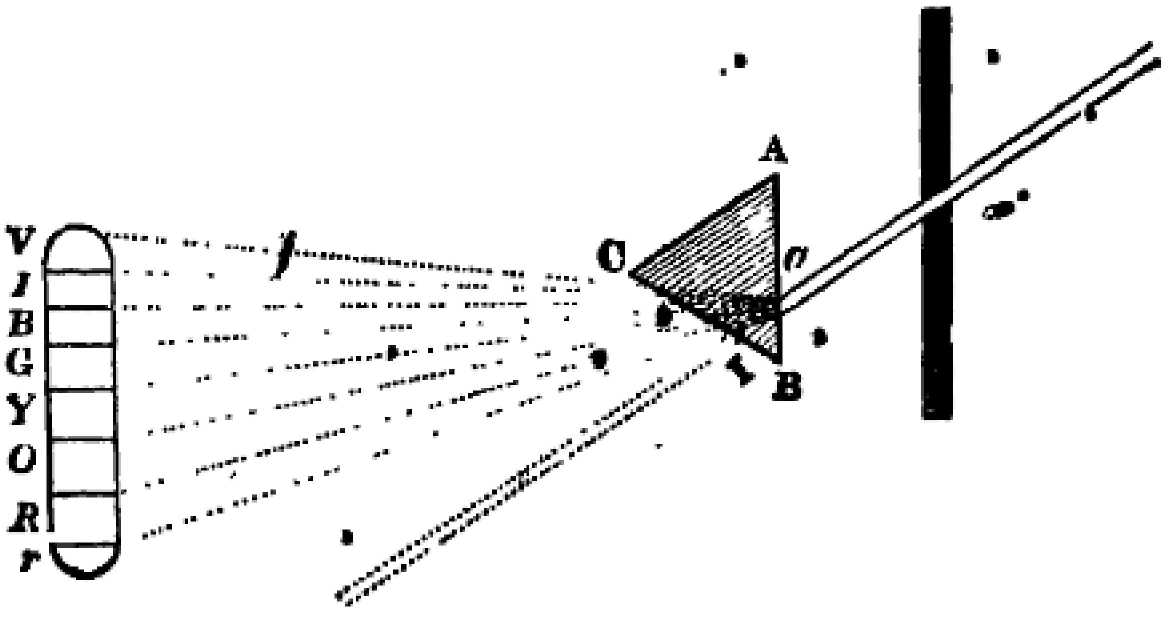


Fig. 11.

surface C I at the same angle, the white beam which fell originally at *a* is altered in direction, or it undergoes refraction, and an oblong coloured figure, which is a distorted image of the sun, is produced upon any screen placed to receive it. This image is called the *solar spectrum*, or the *prismatic spectrum*, and has usually been regarded as consisting of seven rays—*red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*, indicated in the diagram by the respective initials; *r* or extreme red being added. Sir Isaac Newton conceived that these rays depended upon the angle to which the ray was bent out of its path by the prism, and he conceived that some rays were more susceptible of this deviation than others, *i.e.* that a violet or a blue ray was in a condition to suffer a greater degree of refraction than a red ray or a yellow ray. His expression of the law which he imagined was a true explanation of the phenomena was to this effect—*a given angle of refrangibility indicates a given colour—a given colour argues a given angle of refrangibility.* There are some reasons, however, for doubting the entire correctness of this Newtonian hypothesis.

10. If we look at the prismatic spectrum through a piece of glass stained blue with the oxide of cobalt, we discover another ray below the ordinary red ray, which is of a very beautiful crimson. This ray is usually termed the extreme red, or the crimson ray. If the spectral image is thrown upon a piece of paper stained with some vegetable yellow, as turmeric, a new ray becomes visible, at the most refracted end, beyond the violet, to which the name of the *lavender ray* is given, although its colour may be regarded as a neutral grey. Modern research has still enlarged the prismatic spectrum. There are several solutions, such as those of sulphate of quinine, of the astringent principle of horse-chestnut bark, or, some of the resinous oils obtained from coal-tar, a green variety of fluor-spar, and a peculiar yellow-glass usually termed Bohemian canary-glass, which possess the remarkable property of *transmitting* either white light, or light coloured in correspondence with the colour of the medium through which it is transmitted, while they disperse from their first surfaces rays of a colour totally different, these being either blue, purple, or green. If the prismatic spectrum is thrown upon these dispersive surfaces, we discover the remarkable fact, that these rays have a much higher degree of refrangibility than any luminous rays with which we were acquainted. They appear beyond the Newtonian spectrum, forming, as it were, a new spectrum, shining with a peculiar phosphorescent light. This peculiar effect has been called *fluorescence*, from the circumstance that fluor-spar exhibits the phenomenon in a striking manner.

11. It will be evident, from this statement, that white light may be decomposed into more than seven

coloured bands. We may now reckon ten or more, which we enumerate, (fig. 12,) commencing with the least refrangible, and proceeding to those of the highest refrangibility.

The crimson ray; red, orange, yellow, green, blue, indigo, violet, lavender; and the fluorescent rays, which are seen as celestial blue, pea-green, or purple.

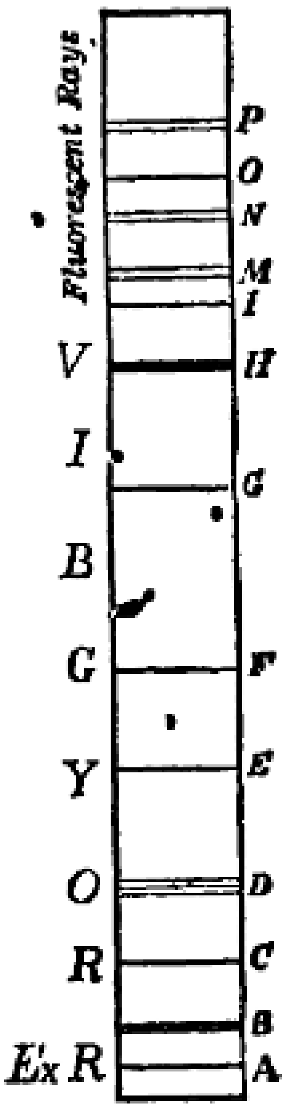


Fig. 12.

12. There is, however, every reason for believing that many of these rays are but combinations of some of the others. It is thought the orange may be due to a mixture of the red and the yellow, that the green band may be produced by the blending of the yellow and the blue. Indeed, Sir David Brewster and some others, consider that white light consists of only three primary rays, red, yellow, and blue, the other rays resulting from the intercombination of these rays. The subject is, however, still under examination. Certain it is that white light consists of several coloured rays—that the coloured rays are manifested by refraction, and that by recombination we can reproduce white light; for if we place a second prism against the face of the first, the rays are recombined, and a white spot of light is produced. Or we may recombine the rays, and thus produce white light by means of a lens. The illuminating powers of these rays are very different; the greatest intensity of light exists in the yellow ray while it diminishes towards either end. Of course *white light* has a greater degree of illuminating power than any one of the coloured rays, since the entire reunion of all the rays is necessary to produce whiteness.

13. If we interrupt any one ray, we produce colour. Thus if we stop the violet rays, the light will become

yellow; or if we interrupt the blue or green rays, we shall produce different tints of redness: on the contrary, if we check the passage of the red, and the other rays at the least refrangible end, we produce every shade of green, blue, and violet. In this way we may imitate every tint in nature, and that, too, with a perfection and brilliancy which cannot be matched by art. If these experiments are tried on a sheet of white paper, they afford a satisfactory explanation of the colour of natural objects, and confirm the truth of Newton's hypothesis, that *the colour of natural bodies are not qualities inherent in the bodies themselves by which they immediately affect our sense, but are mere consequences of that peculiar disposition of the particles of each body, by which it is enabled more copiously to reflect the rays of one particular colour, and to transmit, stifle, or absorb the others.*

14. In producing a very pure prismatic specimen, by means of a perfect glass prism, which decomposes the line of light admitted through a fine slit, some new and curious conditions attract attention. It is then discovered that the chromatic bands forming the spectrum are crossed by a great number of black lines—spaces, in which there is an entire absence of light. These spaces were first observed by Dr. Wollaston, but from their having been carefully examined by Fraunhöfer, of Munich, they are commonly called *Fraunhofer's dark lines*. In figure 12, a few of the more important dark spaces alone are marked, with the letters attached by which they are designated. The causes which lead to these interruptions in the spectrnm are unknown; it is not improbable but they may be referred to the absorption of rays by the medium through which the light passes, in its passage from the sun to the earth.

15. In considering the phenomena of light, the peculiar conditions of *Double Refraction* and *Polarization* must not be omitted.

The *double refraction* of a ray of light, that is, the splitting of it into two rays, takes place when the medium through which the light passes is of unequal density, or in which the arrangement of the particles constituting the mass is subject to variations. The most remarkable body in nature possessing this power is Iceland spar. Let A B C D fig. 13, represent a crystal of this substance, if L is a ray of light falling upon it, it will within the crystal split into two rays, *l l*, and form two spots of light upon any screen placed to receive them. If instead of this we place the crystal on a piece of paper marked with a black stripe or spot, and look through it, two stripes or spots will be seen; these two images are called the *ordinary* and the *extraordinary* ray: on turning the crystal, one will be seen to revolve around the other. Although Iceland spar possesses this power in a high degree, a great number of bodies have the same power under certain conditions, and amongst others the crystalline lenses of the eyes of most animals are endowed with this property.

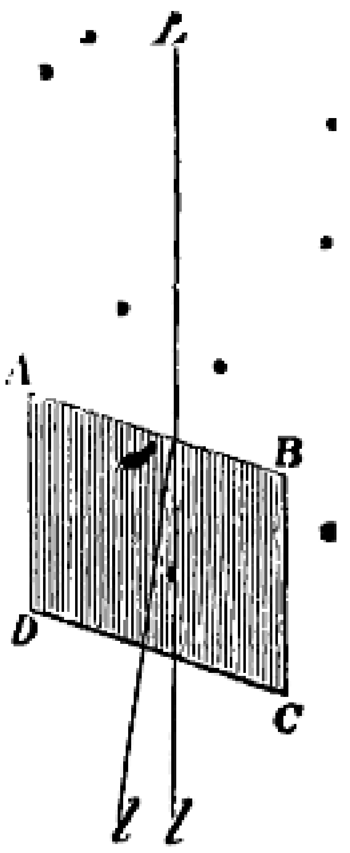


Fig 13.

16. It is not easy within our prescribed limits to give a clear explanation of the *polarization of light.* An account of its discovery will convey the best impression of some of its phenomena. A French philosopher, M. Malus, was looking at the light of the setting sun reflected from a window in the Luxembourg Palace, through a prism of calcareous spar. He found that when he held the prism in one position he saw the golden rays most perfectly, but that if he turned the prism round through a quarter of a circle, although he continued to see the window, all the light which was previously reflected so brilliantly had disappeared. Upon turning the prism round another 90° the rays passed as freely as before, but upon turning it through another similar space, the rays were again extinguished. The

light was here reflected from the surface of glass in the window at an angle of 56°. Now, if we place a plate of glass at this angle and receive a ray of light upon it, the reflected beam and the transmitted beam will be found to be altered in their conditions. They will have undergone *polarization.*

17. An *ordinary ray* of light will pass through a transparent plate of glass in whatever position it may be placed relative to the incident beam, the *polarized ray* will not pass through it in all positions. An *ordinary ray* is likewise reflected in all positions; from the reflecting-glass a *polarized ray* is not reflected in all positions of the mirror. A *polariscope* (fig. 14), as the instrument is called for producing these conditions, is easily constructed: take two tubes, A and B, the one fitting within the other, and hence capable of revolving; fit on to the end of A a plate of glass not quicksilvered, and capable of turning round so that it may form different angles with the axis of the tube, a similar plate of glass is fixed on to the other tube, B. By an arrangement of this kind the two plates of glass can be placed in any position relative to each other. If we let a pencil of light, L, fall upon the glass A, at an angle of 56° 45′, and let the glass be so placed that the reflected ray will pass along the axis of the tubes and fall

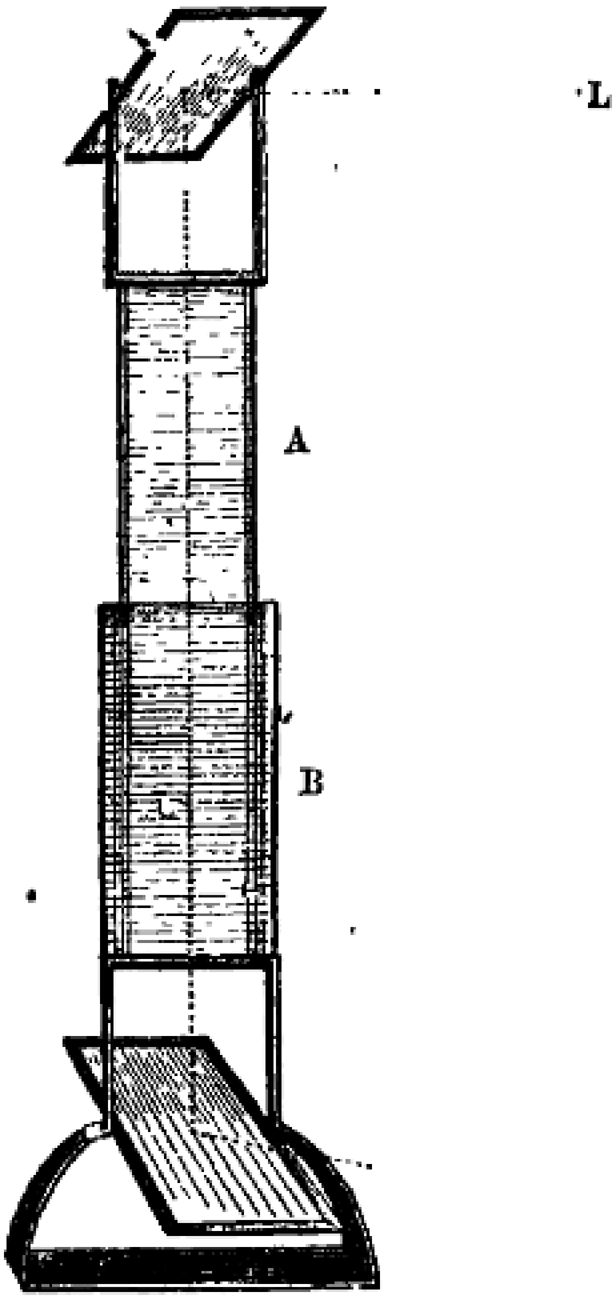


Fig. 14.

on the second plate B, also at an angle of 56° 45′, it will be found on turning this round that there are two positions in which none of the rays are reflected, although in other positions the reflection is more or less perfect. The light has undergone polarization. It is not easy to explain what really takes place; the explanation usually given is of this order. Each ray of common light progresses with two systems of vibration, one wave moving in a horizontal plane, and the other in a vertical plane; the act of polarization is the separation of these two systems from each other, and hence it is that the horizontal wave is only reflected or transmitted in certain positions of the reflecting or the transmitting body, and the same with the vertical wave. Whether this be a correct explanation or not, the phenomena of the polarization of light are amongst the most beautiful with which physical optics has made us acquainted. Spectra, far more intense and beautiful than those produced by ordinary light, are produced, and forms of the most remarkable, but at the same time symmetrical character, mark the path of the polarized rays through transparent bodies.

18. Our knowledge of polarized light enables us to trace out the molecular constitution of transparent bodies, and to determine the lines along which the particles of matter have arranged themselves to form crystals. Numerous practical applications have also been made of the phenomena; the sugar refiner and the cultivator of beet-root for the manufacture of sugar determine, by its aid, problems of much importance to them; the medical man discovers by it conditions of health and disease, which he could not otherwise detect; to the surveyor it becomes the means by which he can calculate the depth of water over a shoal at a safe distance from it; and it enables the astronomer to determine whether the stars are suns, shining with self-emitted light, and to define the luminous conditions of even the Cometary Nebulæ which fly so rapidly across the immensity of space.

LESSON XXI.

HEAT AND CHEMICAL POWER.

1. **Heat.**—The warmth of the solar rays every one must have observed, and experience teaches us that the variations of the seasons are mainly due to the increase and decrease of the heat-rays which are associated with light. If we place a red and a blue glass in the sunshine with delicate thermometers behind them, the highest temperature will be attained by that one on which the rays passing the red media fall. An observation of this sort led Sir W. Herschel to measure the temperature of the prismatic rays. This he did by placing very sensitive thermometers across the coloured rays already described. The experiments made gave the following results:—

In the blue rays the heat was 56°
,, green ,, ,, 58°
,, yellow .. ,, 62°
,, red .. ,, 72°
Below the red .. ,, 79°

Therefore it was proved that the greatest heat existed in the least refrangible rays, where they cease to give light.

2. A very pretty experiment by Sir John Herschel shows this in a yet clearer manner. A piece of thin paper, blackened on one side, is placed so that the prismatic spectrum falls on the unblackened side, which is then washed with strong ether. When any body dries unequally it reflects light unequally; the dry parts becoming white, while the wet portions appear gray. The spectrum dries out such an image as that represented. (Fig. 15.) The spot *r* corresponds with a space a little

below the red ray of the spectrum, and the diminishing action of the heating rays is indicated by the elongated cone between *r* and *c*. By this experiment it is proved that heat rays exist yet lower, and the spots *a b c* indicate rays of considerable thermic power, which are scarcely at all refracted by the prism. From this we learn that the maximum points of light and heat in the spectrum are not coincident, and that the refracting powers are widely different.

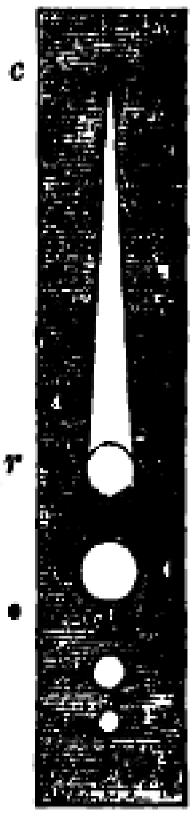


Fig. 15.

3. We have the power of separating the heat and the light rays from each other by absorbent media. A slice of black mica, or of obsidian, obstructs nearly all the light, but all the heat freely passes; on the contrary, a glass, stained green with oxide of copper, scarcely interferes with the passage of light, but stops nearly all the rays which possess any heating power, and more particularly those which are the least refrangible. Glass slightly tinged green by copper has been employed, at the suggestion of the author of this paper, in glazing the Palm-house in the Royal Botanic Gardens at Kew, for the purpose of preventing the action of the most scorching of the solar rays on the plants, and it has proved eminently successful.

4. Chemical power.—If the sun's rays fall upon some preparations of silver, which are white—as the chloride of silver—they change colour, and become nearly black. This power of producing chemical change, or of effecting the decomposition of the metallic salt exposed to solar influence, is one of the most remarkable phenomena which have engaged the investigations of men of science. It cannot be doubted, but that through all time, men must have observed that some colours were bleached, and that others were darkened by the sunshine; but no one appears to have inquired into the phenomena. At length the alchemists observed that the solar rays

changed the colour of some salts of silver. They were then disposed to believe that gold was silver, "pierced through with the sulphurous principle" of the sunbeams, and they believed themselves near the discovery of the principle of transmutation, in search of which they wasted their lives. From this false interpretation of a remarkable fact, no progress was made until about the latter end of the eighteenth century, when a young Swedish chemist discovered that chloride of silver was not blackened equally by all the rays. Scheele's experiments and observations were repeated and confirmed; it was proved that all the least refrangible rays—the red, orange, and yellow rays—produced no change in the colour of this salt, but that the most refrangible—the blue, violet, and rays beyond this space,—were most chemically active.

5. If a paper covered with chloride of silver is exposed to the action of the prismatic spectrum, it begins to darken in the blue ray, and the darkening extends with rapidity to the end of the violet; it is continued some considerable space beyond the spectrum where there is no light. By long exposure the red ray effects a slight chemical change, but the extreme red ray produces none. There are two or three points which must be remembered. By the diffused light which is always present, when such an experiment as this is made, the paper is tinted over every part but two spaces, one where there is the most heat *a*, and the other where there is the most light *b*, are preserved absolutely white and unchanged; the greatest change taking place at *c*. These three dissimilar maxima will be best understood by the following diagram, (fig. 17,) where the three curved lines represent respectively the variations of intensity,

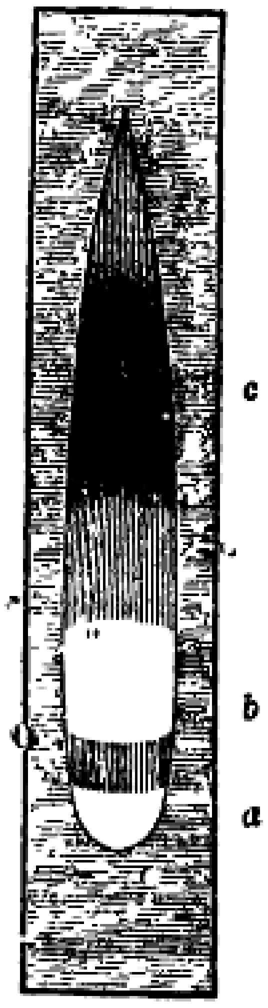


Fig. 16.

and the maxima of luminous power L, of heating power H, and of chemical action C. As we can separate light and heat from each other, so can we exhibit the luminous and the chemical forces apart. If we take a solution of the yellow bichromate of potash, we shall find that no chemical rays permeate it, although the light shines through it with much brilliancy; and chloride of silver, placed in full sunshine behind such a transparent medium, undergoes no change. But if we take a deep purple solution of sulphate of copper and ammonia, although scarcely any light passes it, we shall discover that chloride of silver will blacken as readily behind it, as if it was exposed to the full sunshine,—because the chemical rays pass it freely.

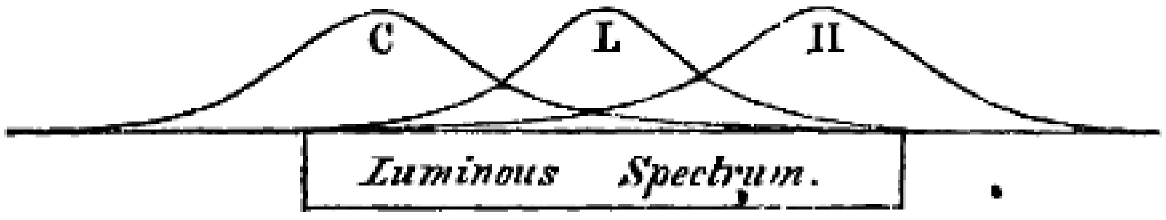


Fig. 17

6. It is yet to be decided whether those three principles are modified forms of one, or whether they are dissimilar agents united in the sunbeam. We have three very distinct phenomena; these are *light*, *heat*, and this chemical power, to the cause of which the term *actinism* has been applied. This last power or principle is that by which is produced all the variety of pictures grouped under the general term of *photographic drawings*. Pictures are obtained upon silver plates, on glass, and on paper, and for their production a preparation known as the iodide of silver, is usually employed. The pictures are obtained in two ways—first, by placing the leaves of plants, engravings, or anything else which we desire to copy on the prepared surface, pressing them close with a plate of glass, and exposing directly to the sunshine, when all the exposed parts darken, leaving the spaces covered unchanged, or only changed in proportion to the

quantity of light which penetrates the superposed body; or second, by the use of the camera obscura. The images of external objects falling on the prepared surface, produce a change exactly proportional to the quantity of chemical radiations proceeding from the external object. These pictures are then developed or exalted by the application of some chemical compound, possessing the required power, and fixed or rendered permanent by employing another chemical material, which has the power of dissolving all the silver salt which remains unchanged.

7. PHOSPHORESCENCE.—This term is applied to the emission of light from any body, under peculiar circumstances. The whiting, and some other fish, speedily assume this condition. Many varieties of decayed wood, in like manner, glow in the dark. Phosphorus, combining with the oxygen of the air, undergoing indeed slow combustion, shines brilliantly in the dark, hence the term phosphorescence. There are two substances, combinations of sulphur and lime or barytes—known as Canton's and Baldwin's phosphorus; which being exposed to the sunshine, and then carried into a dark room, give out a considerable quantity of light. This appears to show something like the absorption of the solar rays, and their subsequent emission. Yet it is curious that the effect is due to those rays of the spectrum which possess the least illuminating power. If either of these solar phosphori, when smeared over paper, be exposed to the action of the prismatic spectrum, it will be found that they only become luminous upon the spaces covered by those rays which are most chemically active—all the other parts continuing perfectly dark. This proves either that the chemical rays excite this phosphorescent power, or that it is due to those extra-spectral luminous rays, which have been described as becoming visible in sulphate of quinine solution, or in uranium glass. We know the conditions by which the phenomenon can be brought about, but the cause producing it is involved in mystery, notwith-

standing the long and earnest investigations which have been made from time to time by the most eminent scientific observers.

8. NATURE OF LIGHT.—The excitement producing vision is explained, by one of the two theories of light, which we have avoided mentioning until the chief phenomena of this agent had been described. Sir Isaac Newton supposed light to be an emission of infinitely fine particles of matter from the sun, these particles travelling at the enormous rate of more than 190,000 miles in a second of time. In consequence of this velocity, notwithstanding the particles are supposed to be 1000 miles apart, they appear as a continuous stream. Matter was supposed to exert certain forces, by which the eye was protected from injury by the beating of light upon its membranes, or passing through its lenses, and the phenomena of colour, &c., were explained upon the hypothesis of variations in the rates of progression.

9. The undulatory theory, as it is termed, supposes all space to be filled with a peculiar attenuated medium called *ether*, which interpenetrates even the most solid masses of matter. When, by the action of some force, this is put in motion, such motion being a system of waves or undulations, light is the result.

Colour, as exhibited by the prismatic spectrum, this theory supposes to be due to different lengths in the wave, and variations as to the number of undulations in a given time.

Beyond this, according to the undulatory theory, a certain amount of wave-motion is supposed to produce *heat*. This being increased, *light* is the result; and, eventually, the vibrations still increasing, the power of producing *chemical* change is obtained.

10. Most luminous phenomena can be explained upon either theory; but the conditions of the polarization of light are more satisfactorily elucidated by the hypothesis of undulations.

11. The consideration of the action of the principles, heat, light, and chemical power, involved in the solar

beam in producing the great phenomena of creation, opens a wide and interesting field of inquiry. The first spring of life in the germination of the seed has been proved to be due to the chemical power of the sunbeam; the growth of the plant and the formation of wood to the light; and the process of flowering and the perfection of the fruit to the solar heat rays. The animal, like the vegetable economy, depends for its very existence on light. Before its creation the world was a chaos: but God said, Let there be light: and organization, life, and beauty at once overspread the face of the earth.

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